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CRITICALLY LOADED HOLE TECHNOLOGY
ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

John B. Kohls

Metcut Research Associates Inc.
3980 Rosslyn Drive
Cincinnati, OH 45209

March, 1980

TECHNICAL REPORT AFWAL-TR-80-4027
FINAL REPORT PERIOD 27 December 1977 - 27 October 1979

MATERIALS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OH 45433

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This technical report has been reviewed and is approved for publication.

Robert B Urzi

ROBERT B URZI
Engineering and Design Data
Materials Integrity Branch

Clayton L Harmsworth

CLAYTON L HARMSWORTH
Technical Manager
Engineering and Design Data
Materials Integrity Branch

FOR THE COMMANDER

T D Cooper

T D COOPER, Chief
Materials Integrity Branch
Systems Support Division
Materials Laboratory
Air Force Wright Aeronautical Laboratories (AFSC)

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John B. Kohls (Metcut Research)
Stephen C. Ford (Battelle-Columbus Labs)
George Roth (Univ. of Dayton Research

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A pilot test program was conducted which consisted of a coordinated test activity between interested AGARD SMP member countries. The program leads to a more uniform attitude toward fatigue testing and evaluation of critically loaded hole parameters among its participants. This report describes the U.S. portion of the test program. The report includes both open hole and low load transfer joint testing of specimens having both high and low quality test holes. The quality level of the holes was based primarily on cost. The report also includes a technique for verifying the loading accuracy of the spectrum fatigue equipment used by each of the participants.

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FOREWARD

A thirty (30) month pilot test program was conducted which consisted of a coordinated test activity between interested NATO/AGARD SMP member countries including Sweden as a non-member country. This pilot program lead to a more uniform attitude toward fatigue testing and evaluation of critically loaded hole parameters among its participants. This report describes the US portion of a complex test program where each new phase was initiated after the successful completion of the previous phase. The program was conducted under Air Force Contract No. F33615-78-C-5030. The program manager for the Air Force Wright Aeronautical Laboratories was Mr Robert Urzi. The prime contractor was Metcut Research Associates Inc. in Cincinnati, Ohio under the direction of Mr John B Kohls. Subcontractors to Metcut were: Battelle-Columbus Laboratories (Mr Stephen Ford) in Columbus, Ohio which conducted all spectrum fatigue testing and University of Dayton Research Institute (Mr George Roth) in Dayton, Ohio which performed the load verification effort.

Contribution of fastener equipment and installation techniques included Messrs. Paul Pagel of Kaynar, Fullerton, California and Patrick Meade of Monogram/Aerospace Fasteners, Los Angeles, California.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

SECTION I

PROGRAM DESCRIPTION

1. PHASE 1

The aim and purpose of Phase 1 and Phase 1A (Phase 1 repeat) was to substantiate the thesis that in spite of idiosyncrasies in fatigue testing occurring in widely separated mechanical testing laboratories, fatigue testing of identical specimens, utilizing similar testing parameters, e.g. load history, physical/chemical environment, etc., would lead to mutually agreeable conclusions. The thesis was stated with the stipulation that all test samples were identical in physical, mechanical, and geometric properties.

2. PHASE 2

From the data submitted on Phase 1 and preliminary analysis of the data, a major restructuring of the Pilot Test Program took place. Added to the program was a complete replication of the Phase 1 test effort. This replication took place concurrent to the Phase 2 test activity. Phase 2 was modified as to content and level of effort required. Retained from the original program was the definition of two levels of hole quality (cost) reflecting each participant's aerospace industry. Taking advantage of the Phase 1 results and with the replication of the Phase 1 testing, the concept of round-robin testing was not used for the Phase 2 activity. It was felt that the homogeneity of variance exhibited in Phase 1 data which was further densified by repeating the Phase 1 tests enabled each country to work independently in Phase 2. However, common materials and a single source of specimen blanks was used in Phase 2. Each participant fabricated their own test coupons from specimen blanks provided by the

U. S. Each participant fabricated six specimens containing a high quality (cost) hole and ten specimens containing a low quality (cost) hole. These specimens were subsequently fatigue tested as "open hole" coupons.

Concurrently with the tests on the sixteen specimens, six repeat specimens, identical to Phase 1 specimens, were also tested. It was felt that this approach enabled the concept of round-robin testing to be dropped. This approach also provided a better basis for the unaltered concept of the Phase 3 program. It enables the participants to compare the ratios determined in Phase 3 with those arrived at in Phase 2. In addition to retaining the original scheduling proposed for Phases 2 and 3, this concept provided a reduction in the total number of specimens manufactured and tested by each participant.

3. PHASE 3

In this phase the work developed into separate programs, each program being undertaken by one participant and being complete in its own right. Each participants program determined the fatigue performance of one (his choice) structural fatigue rated fastener system installed in a high or low quality hole (by his own definition). It also studied a non-fatigue rated fastener alternative of the same static strength assembled with low quality holes. Phase 3 utilized a low load transfer joint specimen, assembled utilizing standard acceptable joining and faying surface practices. However these faying surface conditions and specimen geometry were identical for all participants.

SECTION II

MATERIAL AND SPECIMENS

The material used on the AGARD SMP Critically Loaded Hole Technology Program was 7050-T76 wrought aluminum alloy. This material was received in mill rolled sheets approximately .197" x 44.5" x 96" in size. There were two heats of material on the program. Heat No. 1 designated as Lot 302-791 was used in Phases 1, 1A, and 2 test activity. Heat No. 2 designated as Lot 219-521 was used only in Phase 3. The chemical composition and mechanical properties as supplied by the basic metal producer (Aluminum Company of America) are given in Table 1. Since the specimens were to be tested in the "as received" or "as milled" condition, the sheets of aluminum alloy were procured with protective coating on each side to prevent scratching or other surface blemishes during shipment.

Sketches showing the layout of the specimens used on the program are presented in Figures 1, 2, and 3. The specimen lengths were cut out using a Grob band saw cutting at approximately 300 ft./min. After cut out, the edges, both length and width, were face milled using the conditions given in Table 2. This was followed by contouring the gage section area per the condition given in Table 3.

The test hole, located in the center of the gage section was produced with a variety of techniques over the three phases of the program. Phases 1 and 1A test holes were drilled plus double reamed. Phases 2 and 3 used high and low quality holes per consensus of U. S. Aerospace Standards. The procedures for producing these holes are given in Table 4.

The basis for defining high and low quality was cost. The high quality holes were produced by a technique to simulate a Gemcor or other heavy duty automatic drilling machine. A Cincinnati Cinova 80 milling machine was used to assure spindle rigidity similar to a Gemcor. The drill runout did not exceed $\pm$ .0005 inch. The specimen to be drilled was securely clamped to the machine tool table with a clamping pressure greater than 170 psi. The specimen was located on a special fixture to insure that the test hole was central with respect to both axis of the specimen. The drill geometry and machining conditions are given in Table 4. It is important to note that the high quality condition included a positive power feed rate and spray mist cutting fluid. After drilling, the test hole was not deburred.

The low quality holes were produced on a light duty, tool room type drill press. The specimen to be drilled was not clamped to the table, but allowed to "float" during the drilling operation. A standard jobbers length drill was used with a heavy manual feed rate. The drilling operation was performed without the use of a cutting fluid.

After drilling the low quality test hole but before the drill was extracted from the hole, the spindle was stopped. The drill was then extracted from the hole without rotating. The buildup that had collected on the cutting edges of the tool was allowed to rub along the test hole surface. The geometry and drilling conditions used to produce the low quality holes is given in Table 4.

After fabricating the holes for specimens used in Phases 1, 1A, and 2, the edges of the gage area were radiused using a carbide form cutter having a 1/32" radius. This operation was followed by longitudinal polishing of the gage area using 180 grit aluminum oxide paper. Test specimens were shipped to each participant listed in Table 5. Each country listed received: (1) specimens, (2) an explanatory letter, and (3) a packing slip identifying their particular specimens. A copy of the letter sent to each participant is given in Appendix A.

The Phase 2 specimen configuration was the same as for Phases 1 and 1A specimens. However, the center hole specimen blanks for Phase 2 testing had only a 1/16" pilot hole. These Phase 2 specimens were completed to the final configuration by the individual participants. Along with the specimens for Phases 1A and 2, two 4' x 8' aluminum plates were shipped to each participant for use in the manufacture of joint specimens to be tested in Phase 3.

Figure 4 is a sketch of the packaging of the aluminum plates and test specimens for Phase 2 shipment. A 1/2" sheet of plywood, 4' x 8', was laid on three 2" x 4" rails. The two aluminum plates (4' x 8') were then laid on the top of the plywood. A second sheet of plywood covered the aluminum plates. This second sheet of plywood had a pocket cut out of the center for locating the specimens. A 1/8" piece of plywood was first put into this pocket to separate the aluminum plates from the test

specimens. The specimens were placed on top of this 1/8" sheet and covered by another 1/8" sheet. This entire package was then covered by a third 1/2" sheet of plywood and fastened in place by steel strapping. The cross section of this stack up is given in Figure 4. This packaging procedure insured that the surface of the test specimens would not be blemished during shipment.

The specimens used in the Phase 3 portion of the program were low load transfer joint (reverse dogbone) specimens. A sketch of the specimens configuration is shown in Figure 5. These specimens received a faying surface sealant. This sealant was PR-1431-G and was manufactured by Products Research & Chemical Corporation, Gloucester City, NJ. The specification for use and description of this product as supplied by the sealant manufacturer is given in Appendix B. A procedure for installing this sealant on the fay surface was sent to each of the participants. This procedure is also given in Appendix B.

The phase 3 specimens were of three varieties:

1. High quality hole with a fatigue enhancement fastener (K-Lobe fastener system manufactured by the Kaynar Company)

2. Low quality hole with a fatigue enhancement fastener (K-Lobe)

3. Low quality hole with a blind rivet (VisuLok manufactured by the Monogram Fasteners, a division of Monogram Industries)

The table giving the specimen number along with hole diameter and interference or clearance value for each of the specimens tested in Phase 3 is given in Table 6. The test results for Phases 1, 1A, 2, and 3, are given in reports by the Battelle-Columbus Labs. These reports are in Appendices C, D, and E, respectively.

A final portion of the program was the verification of loading accuracy for the Falstaff load sequence. This work was performed by the University of Dayton Research Institute (UDRI). Personnel from UDRI visited each of the participants and monitored their spectrum fatigue test equipment during test using the Falstaff load sequence program. A report on this load sequence and load level verification is given in Appendix F.

CONCLUSIONS

1. The use of widely separated and different National test facilities following the same basic test procedures and test techniques can lead to mutually agreeable test results among investigators provided there is a formal agreement prior to fatigue testing.

2. The need for round-robin testing can be minimized or even eliminated providing certain parameters are kept constant or provided to each individual participant. Sufficient accuracy checks during dynamic testing are absolutely essential.

3. The terms "high" and "low" quality holes did not lead to equivalent fatigue test results. By U.S. Aerospace Standards for low and high quality holes, the high quality hole leads to substantially longer test lives during the Phase 2 "open hole" program.

4. The results obtained during the Loading Verification activity provided data that the testing organization applied the correct loads of the Falstaff Spectrum in conducting fatigue tests for Phase 3 of this pilot program.

5. The use of the Kaynar K-Lobe fastener system leads to equivalent fatigue lives in testing low load transfer joint specimens when using both the low level and high level of hole quality. K-Lobe fasteners

were installed in interference fits ranging 0.0041 to 0.0045 inches in high quality holes and interference fits ranging from 0.0036 to 0.0045 inches in low quality holes. The use of a non-fatigue rated blind rivet system in low quality holes leads to very short fatigue lives. Those blind rivets were installed in clearance fit holes of low quality.

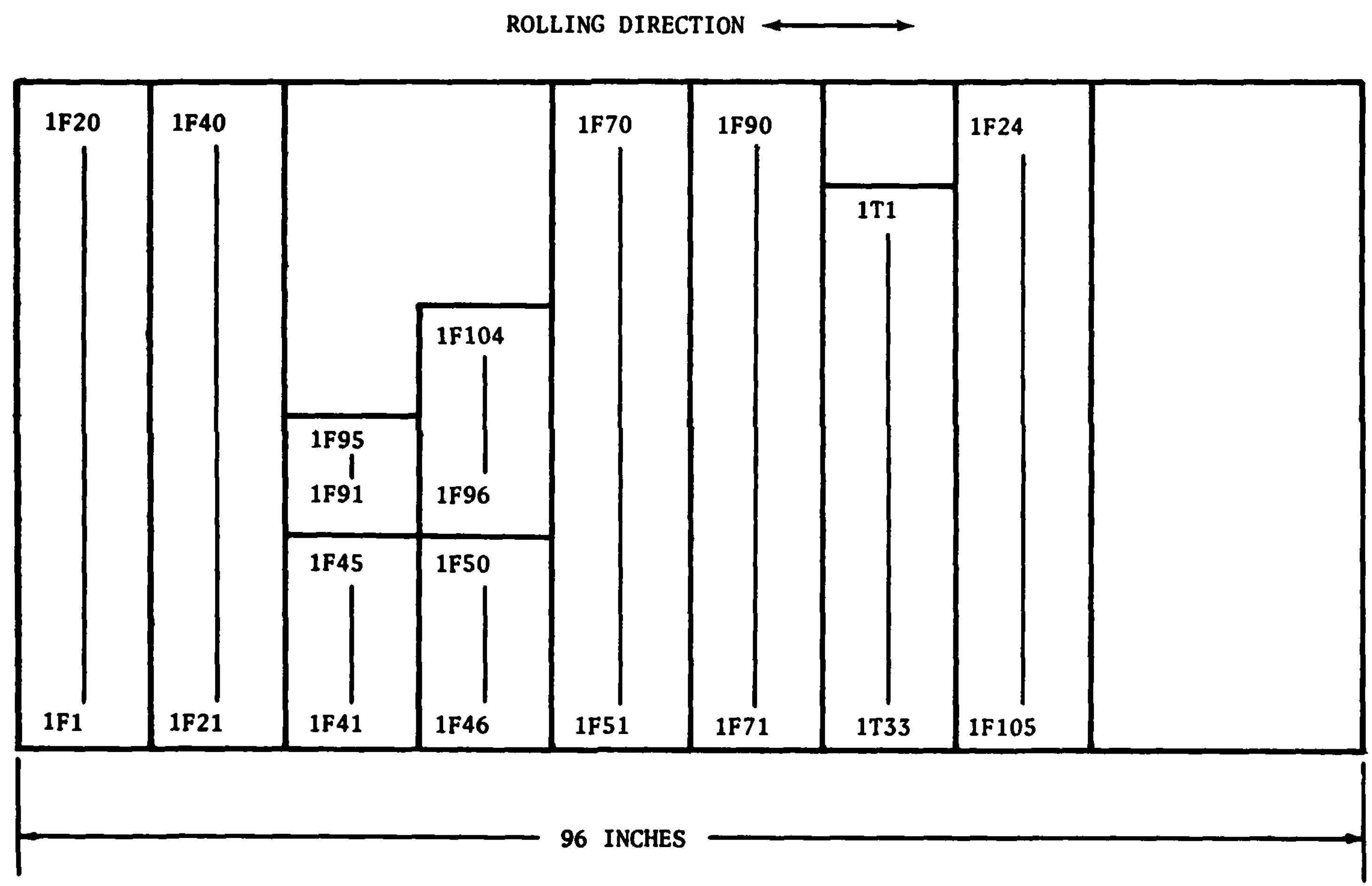

Figure . - Test Coupon Layout - Phase 1 Specimens

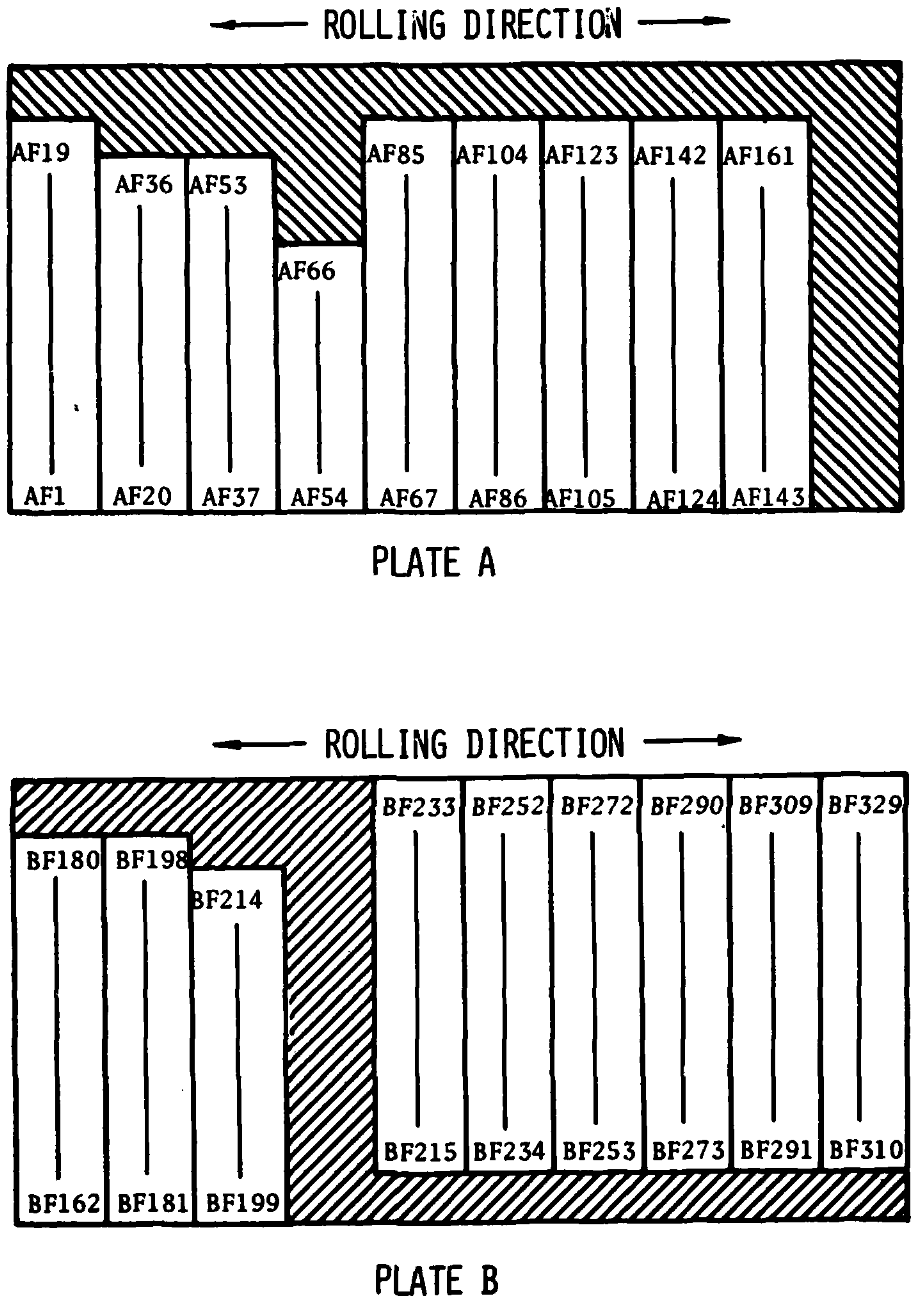

Figure 2 - Test Coupon Layout - Agard - Critically Loaded Hole Technology Phase 2

LONGITUDINAL ROLLING DIRECTION

←→

J4	J3	J2	J1
J8	J7	J6	J5
J12	J11	J10	J9
J16	J15	J14	J13
J20	J19	J18	J17
J24	J23	J22	J21
J28	J27	J26	J25
J32	J31	J30	J29
J36	J35	J34	J33
J40	J39	J38	J37
J44	J43	J42	J41

44 of 46 Pieces
#J1 - J44

LONGITUDINAL ROLLING DIRECTION

←→

J56	J45
	J46
	J47
	J48
	J49
	J50
	J51
	J52
	J53
	J54
	J55

12 of 56 Pieces

#J45 - J56

Figure 3 - Test Coupon Layout - Phase 3 Specimens

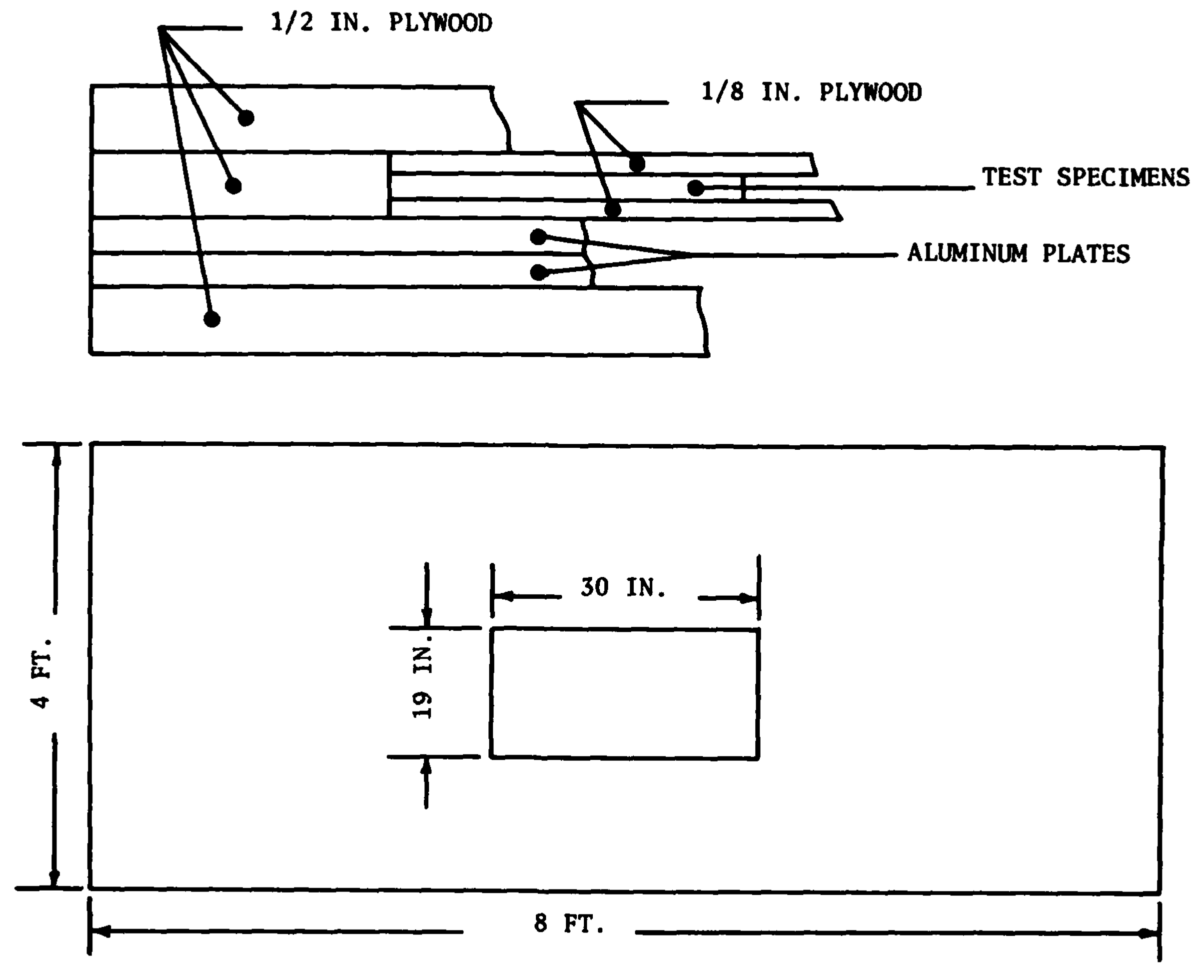

Figure 4 - Schematic of Packaging for Phases 1A and 2 Specimens and Phase 3 Material

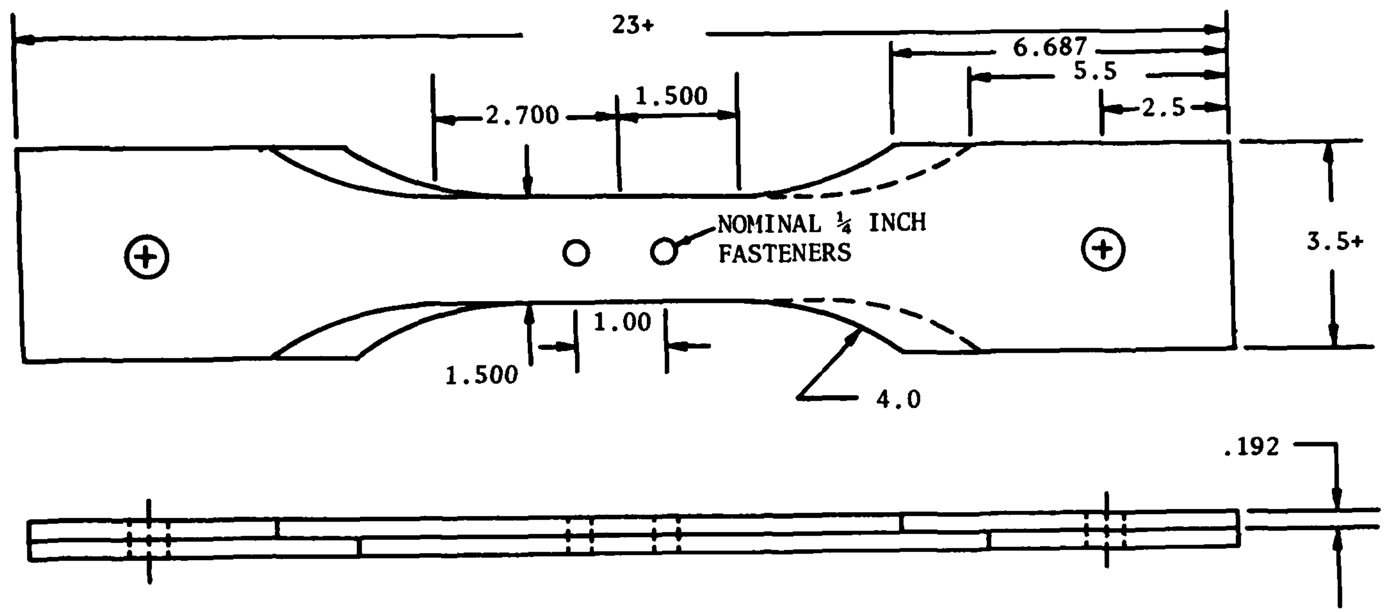

Figure 5 - Reverse Dogbone Specimen Used for Phase 3 (All Dimensions are in Inches)

TABLE 1

MECHANICAL PROPERTIES 7050-T76 ALUMINUM ALLOY

	Phases 1, 1A, 2 Lot 302-791 First Shipment		Phase 3 Lot 219-521 Second Shipment	
	Max.	Min.	Max.	Min.
Tensile Strength, ksi	85.9	85.4	83.7	83.2
Yield Strength, ksi	80.2	79.3	75.7	75.7
Elongation, % in. 2 in.	12.0	12.0	12.5	12.0
Conductivity	-	35.4	-	37.5
Composition	Max.	Min.	Max.	Min.
Silicon	0.12	-	0.12	-
Iron	0.15	-	0.15	-
Copper	2.6	2.0	2.6	2.0
Manganese	0.10	-	0.10	-
Magnesium	2.6	1.9	2.6	1.9
Chromium	0.04	-	0.04	-
Zinc	6.7	5.7	6.7	5.7
Titanium	0.06	-	0.06	-
Zirconium	0.15	0.08	0.15	0.08
Others, each	0.05		0.05	

TABLE 2

MACHINING CONDITIONS USED FOR FACE MILLING THE SPECIMEN BLANKS

Cutter Diameter, in.	6
Tool Material	K68 Carbide
Feed, in./tooth	.004
Cutting Speed, ft./min.	1200
Tool Wear, max.	.006
No. of Teeth	8
Fluid	20:1 Soluble Oil

TABLE 3

MACHINING CONDITIONS USED FOR MILLING THE SPECIMEN CONTOUR

Cutter Diameter, in.	1
Tool Material	M2 HSS
Feed, in./tooth	.0014
Cutting Speed, rpm	950
Tool Wear, Max.	.006
No. of Teeth	6
Fluid	Dry

TABLE 4

DRILLING CONDITIONS USED FOR CENTER NOTCH TEST HOLES

Phases 1 and 1A

1) Drill @ 660 rpm, .002 in. per revolution, 7/32 in. diameter hole
2) Ream @ 660 rpm, hand feed, .243 in. diameter hole
3) Ream @ 660 rpm, hand feed, .251 in. diameter hole

Phases 2 and 3

High Quality

Tool Material = HSS
Diameter = 6.35 mm.
Geometry:
  Point Angle = 140°
  Type Point = Crankshaft (split)
  Helix Angle = 30°
Spindle Speed = 3000 RPM
Feed Rate = .076 M./min.
Cutting Fluid = LPS #1 (Mist)
Type Tool = Heavy Duty Stationary Equipment

Low Quality

Tool Material = HSS
Diameter = 6.7 mm. (for Fasteners, 6.35 for open hole)
Geometry:
  Point Angle = 118°
  Type Point = Crankshaft (split)
  Helix Angle = 30°
Spindle Speed = 800 RPM
Feed Rate = Heavy Manual
Cutting Fluid = Dry
Type Tool = Light Duty Drill Press

TABLE 5

AGARD SMP CRITICALLY LOADED HOLE TECHNOLOGY SPECIMEN NUMBER IDENTIFICATION

	Belgium	France	Germany	Italy	Netherlands	Sweden	Turkey	United Kingdom	United States
PHASE 1									
Tensile	1T4	1T6	1T1	1T22	1T2	1T9	1T27	1T3	1T19
	1T10	1T11	1T8	1T23	1T13	1T12	1T29	1T5	1T24
	1T17	1T14	1T22	1T26	1T15	1T16	1T33	1T18	1T30
Fatigue	1F17	1F48	1F6	1F35	1F31	1F9	1F4	1F20	1F23
(with hole)	1F32	1F50	1F16	1F43	1F33	1F29	1F62	1F22	1F40
	1F38	1F74	1F54	1F57	1F34	1F73	1F63	1F28	1F64
	1F45	1F101	1F100	1F61	1F47	1F96	1F72	1F83	1F77
	1F81	1F109	1F103	1F65	1F67	1F97	1F75	1F113	1F85
	1F99	1F118	1F105	1F82	1F92	1F107	1F78	1F115	
	1F112	1F119	1F106	1F84	1F108	1F114		1F121	
	1F123	1F120	1F124		1F117	1F116		1F122	1F10
Fatigue (w/o hole)	1F94	1F42	1F12	1F98	1F66	1F52		1F93	1F36
Extra									1F37
									1F10
									1F24
PHASE 1A									
	AF27	AF1	AF38	AF3	AF5	AF25	AF64	AF63	AF45
	AF68	AF32	AF42	AF82	AF117	AF29	AF99	AF72	BF183
	AF137	AF48	AF84	BF229	BF206	AF70	BF191	AF75	BF224
	BF240	AF125	BF208	BF238	BF266	BF221	BF258	AF124	BF235
	BF244	AF139	BR296	BF295	BF282	BF259	BF262	BF162	BF242
	BF260	BF264	BF298	BF302	BF291	BF279	BF276	BF288	BF243
Spare	BF181	AF152	AF158	AF19	AF33	BF249	AF135	BF164	AF26
	BF261	BF175	BF278	AF151	BF176	BF265	BF233	AB232	AF47

TABLE 5

(continued)

PHASE 2

	Belgium	France	Germany	Italy	Netherlands	Sweden	Turkey	United Kingdom	United States
	AF4	AF14	AF6	AF21	AF12	AF8	AF11	AF16	AF56
	AF15	AF17	AF30	AF69	AF24	AF9	AF23	AF22	AF71
	AF40	AF31	AF39	AF74	AF46	AF18	AF28	AF55	AF77
	AF51	AF41	AF44	AF87	AF62	AF49	AF34	AF58	AF78
	AF52	AF60	AF59	AF108	AF91	AF89	AF35	AF119	AF88
	AF61	AF80	AF118	AF116	AF101	AF96	AF79	AF133	AF112
	AF102	AF93	AF126	AF155	AF107	AF97	AF94	AF156	AF113
	AF104	AF110	AF129	BF171	AF127	AF145	AF98	BF166	AF114
	AF105	AF143	AF132	BF173	AF140	AF146	AF121	BF207	AF122
	AF109	AF144	BF177	BF182	AF141	AF165	AF154	BF211	AF136
	AF128	BF172	BF217	BF219	BF163	BF167	AF159	BF215	AF138
	BF192	BF174	BF257	BF253	BF189	BF185	BF222	BF220	BF223
	BF274	BF186	BF294	BF255	BF246	BF193	BF225	BF241	BF227
	BF286	BF188	BF300	BF293	BF283	BF210	BF237	BF248	BF228
	BF320	BF194	BF314	BF304	BF284	BF239	BF263	BF280	BF281
	BF325	BF272	BD319	BF311	BF326	BF299	BF315	BF303	BF305
Spares	AF50	AF13	AF73	AF36	AF106	BF226	AF130	AF160	AF43
	AF53	AF148	AF150	AF90	BF184	BF254	AF153	BF195	AF111
	AF76	BF170	BF180	BF216	BF267	BF308	AF157	BF247	AF123
	BF292	BF245	BF218	BF230	BF268	BF310	AF161	BF269	BF179
	BF313	BF322	BF256	BF285	BF270	BF321	BF168	BF277	BF323

TABLE 6

LOW LOAD TRANSFER JOINT
REVERSE DOGBONE SPECIMENS (MIL-STD-1312, TEST 21)
IDENTIFICATION AND CHARACTERISTICS

PHASE 3

Specimen Number	Hole Quality	Fastener	Hole Diameter #1*	Hole Diameter #2*	Nominal Interference #1	Nominal Interference #2
J41/J48	High Quality	K-Lobe (1)	.2472	.2469	.0042	.0045
J20/J42	High Quality	K-Lobe	.2471	.2470	0043	.0044
J8/J43	High Quality	K-Lobe	.2473	.2472	0041	.0042
J2/J17	High Quality	K-Lobe	.2470	.2471	.0044	.0043
J45/J50	High Quality	K-Lobe	.2469	.2469	.0045	.0045
J25/J35	High Quality	K-Lobe	.2471	.2470	.0043	.0044
J4/J33	Low Quality	K-Lobe	.2628	.2629	.0037	.0036
J18/J12	Low Quality	K-Lobe	.2629	.2629	.0036	.0036
J47/J10	Low Quality	K-Lobe	.2623	.2626	.0042	.0039
J22/J26	Low Quality	K-Lobe	.2620	.2620	.0045	.0045
J13/J53	Low Quality	K-Lobe	.2627	.2626	.0038	.0039
J2/J16	Low Quality	K-Lobe	.2621	.2624	.0044	.0041
					Clearance	
J32/J51	Low Quality	VisuLok (2)	.2631	.2633	.0016	.0018
J6/J40	Low Quality	VisuLok	.2630	.2629	.0015	.0014
J5/J55	Low Quality	VisuLok	.2628	.2626	.0013	.0011
J7/J36	Low Quality	VisuLok	.2629	.2625	.0014	.0010
J24/J30	Low Quality	VisuLok	.2630	.2623	.0015	.0008
J44/J54	Low Quality	VisuLok	.2627	.2635	.0012	.0020

* Average of four Readings:

Two in Top Sheet (Max. and Min.)
Two in Bottom Sheet (Max. and Min.)

(1) K-Lobe Pin P/N KLB60V4M7, Ti-6Al-4V protruding head pin with AFN542-4 washer - torqued to 100 in.-lbs., set aside one-half hour and the re-torqued to 125 in.-lbs.

NOTE: Oversize K-Lobes were installed in low quality holes due to hole size requirements for the non-fatigue rated blind bolt system.

(2) Visu-Lok/Jo-Bolt, Monogram blind bolt, P/N PLT210-8-6

A P P E N D I X   A

METCUT

METCUT RESEARCH ASSOCIATES INC.
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The enclosed specimens are to be used on the AGARD SMP Critically Loaded Hole Technology Program per Revision C. The number of specimens enclosed is eight fatigue samples having a 1/4 in. center notch and 21 fatigue specimens having a 1/16 in. pilot hole in the center of the gage area. These specimens are to be tested per Paragraph 2.2.1 of Revision C.

The attached packing slip gives specimen identification and specimen numbers for each portion of the program. For the 1/4 in. center notch specimens, two are identified as spare samples. For the 1/16 in. pilot hole fatigue samples, there are five spares.

All testing results and format for reporting of data should be coordinated through Bob Urzi at Wright-Patterson Air Force Base. Any questions concerning the information generated should go to Mr. Urzi. Thank you for your cooperation.

Sincerely,

John B. Kohls, Supervisor
Surface Technology

for

Robert B. Urzi
USAF Materials Laboratory
Systems Support Division, AFML/MXA
Wright-Patterson AFB, OH
USA, 45433

JBK:ph

Atch.

METCUT RESEARCH ASSOCIATES INC.
3980 Rosslyn Drive, Cincinnati, Ohio 45209 / Teletype: 810-461-2840 / Telephone: (513) 271-5100

Enclosed is the sealant to be used on the reverse dogbone Phase III specimens of the AGARD SMP critically loaded hole technology program. The specification and application instructions are also provided. It is important to the consistency of the program that each participant follow the directions completely for both mixing and application of the fay surface sealant.

Sincerely,

John B. Kohls, Supervisor
Machinability Testing
Metcut Research Associates Inc.
for
Robert Urzi, Air Force Materials Lab.
Dayton, OH 45433

bb

<u>A P P E N D I X   B</u>

SURFACE PREPARATION AND APPLICATION OF PR-1431-G

SURFACE PREPARATION

1. Clean surface with alkaline cleaner.

2. Clean with oil free solvent immediately prior to application (do not use reclaimed solvent).

   Use a progress procedure - clean a small area and wipe dry with clean cloth before solvent evaporates. Apply solvent to cloth not directly to part.

MIXING INSTRUCTIONS FOR STANDARD CONTAINERS

1. Thoroughly stir the accelerator in its container until an even consistency is obtained.

2. Mix the accelerator into the base compound until a uniform color is obtained. Uniformity of mixture will be complete when no gross dissimilarity exists.

3. The best mixing procedure is as follows:

   (a) Thrust a spatula into the material at the 12 o'clock position
   (b) Draw the spatula toward the 6 o'clock position with a slow three second stroke followed by a pause
   (c) After completion of stroke, turn container 15-20 degrees, and begin next stroke. Repeat until uniformity is achieved.

(d) Periodically run spatula around vertical inside wall of the container to remove any unmixed material. Also remove any unmixed material sticking to the spatula and return it to the material. This technique should take about 4-5 minutes.

4. It is mandatory that the temperature of the material be kept below 75°F (24C) during mixing.

Note: Proper mixing and correct proportion are extremely important for maximum result.

APPLICATION INSTRUCTION

PR-1431-G may be applied to faying surfaces by brush or roller. Before the expiration of the assembly life (20 hours), all work on the faying surface should be finished and all rivets or fasteners drawn tight.

To insure that no leak path exists through the sealant and that the faying surface is completely sealed, a small continuous bead of sealant should be squeezed out on both sides of the overlap when fasteners are drawn tight.

CURE TIME IN FAYING SURFACE

The PR-1431-G may be cured in eight days at 75°F (24C) or the cure may be accelerated by curing 24 hours at 75°F plus 24 hours at 130°F (55C).

APPENDIX C

CRITICALLY LOADED HOLE TECHNOLOGY PILOT PROGRAM

BATTELLE
COLUMBUS LABORATORIES
505 KING AVENUE
COLUMBUS, OHIO 43201

February, 1978

PHASE I REPORT FOR PERIOD APRIL, 1977, - JANUARY, 1978
METCUT RESEARCH ASSOCIATES, INC. PURCHASE ORDER NO. 62306

TABLE OF CONTENTS

APPENDIX I

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

A pilot program has been initiated by the AGARD SMP Subcommittee on Critically Loaded Hole Technology in an effort to promote a mutual confidence in fatigue test data generated by participating countries. The successful completion of the program will lead to a more uniform quality of fatigue testing and evaluation of critically loaded hole parameters among its participants. The objectives of the three-phase program are as follow:

- Phase I - Generate baseline, open hole, fatigue data in order to examine laboratory-to-laboratory variations
- Phase II - Reaffirm the exchangeability of baseline data and investigate the effect of hole quality on open hole fatigue specimens
- Phase III - Conduct independent fatigue evaluations of various fatigue-improvement fasteners and exchange data.

Participants in the program included representatives from Belgium, France, Germany, Italy, Netherlands, Sweden, United Kingdom, and the United States. All specimens for the program are to be prepared by Metcut Research Associates, Inc., from a single heat of 7050 material procured from Alcoa in the form of 7050-T76 bare sheet, 0.196-inch (5 mm) thick. Battelle's Columbus Laboratories (BCL) has been designated as the USA testing facility.

The report contained herein details the results of the Phase I effort.

GENERATION OF THE FALSTAFF SPECTRUM

In order to insure that all particpants apply the same cyclic loads, each country was to test specimens under the FALSTAFF (Fighter Aircraft Loading STAndard For Fatigue). The BCL fatigue load control program was generated using the computer program detailed in the definitive description of the FALSTAFF spectrum, dated March 1976. The flight-by-flight load steps were generated on the BCL CDC 6400 main computer and stored on magnetic tape. The load steps were also printed out and checked carefully against the above-noted FALSTAFF description. Zero load was defined to be at load step 7.5269 of the 32 available load steps. A second magnetic tape was generated (compatible with the fatigue laboratory's Hewlett Packard 2100 computer) converting the load steps to percentages of full-scale load. This information was also stored on the laboratory computer disc unit.

PROGRAM CONTROL

This section describes the BCL system and equipment used to apply and control FALSTAFF program loads. In general, the HP 2100 computer provides load steps to a hybrid unit which generates a constant ramp rate function for the MTS 20,000-pound (88,960 N) closed-loop electrohydraulic fatigue machine. A null pacing unit makes a constant comparison of programmed load to load cell output and signals the hybrid unit when the programmed load has been reached, at which time the ramp direction is reversed and a new load is called from the computer. This procedure continues until a preprogrammed number of flights has been reached or until the test specimen fails. A graphic presentation of the program control cycle is presented in Figure 1. A secondary computer subroutine, STATS, makes it possible to determine the flight number, total number of cycles, and percent of a pass through the spectrum completed at the moment of questioning.

Pretest Checks

Prior to initiating the fatigue test program, a spare specimen (without a hole in the test section) was instrumented with two strain gages located near the specimen edge on each face of the specimen. The output of the four strain gages made it possible to determine specimen bending and buckling (if any existed) and to confirm that dynamic loads matched static calibration loads.

Bending Check

Strain gage data were obtained at incremental load steps for loads to an equivalent of 38 ksi (262 MPa) maximum and -19 ksi (131 MPa) minimum. Data were obtained for three loading cycles. The strain-load data were submitted to a linear regression analysis with resulting R^2 statistic values ranging from 1.000 to .9994. Strain values were computed for the load equivalent of 30 ksi (206.85 MPa) gross stress. Analysis of the strain values indicated that the maximum error due to specimen bending was 1.45 percent. Analysis of the compressive load data indicated that no buckling could be detected.

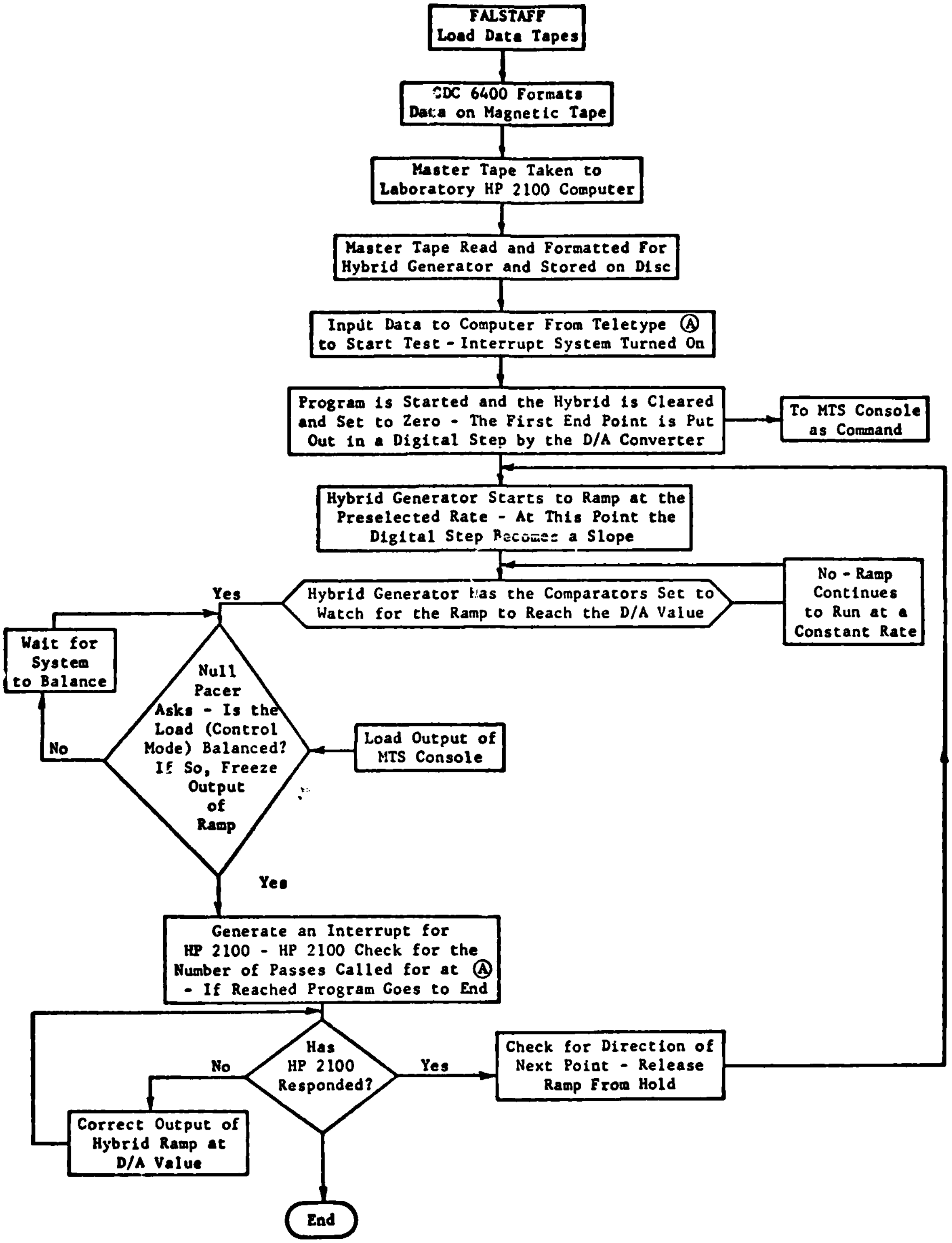


FIGURE 1. PROGRAM CONTROL CYCLE

Static-Dynamic Loads Check

Comparison of strain gage output and calibrated load cell output indicated a maximum axial load error of 1.33 percent at 38 ksi (262 MPa) static load. Application of cyclic loads at the same level provided the same strain outputs.

FALSTAFF Loads Check

The specimen was subjected to FALSTAFF loads cycling and ramp rate and MTS unit controls were adjusted so that fatigue machine load output matched the command signal (reference Figure 2). The controls were not changed during the rest of the test program and the mean cyclic rate was determined to be 10.5 Hz.

TEST RESULTS

Fatigue Test Program

Fatigue test specimens, as supplied by Metcut Research Associates, Inc., were selected at random. The initial specimen 1F37 was cycled at a reference (gross) stress level of FALSTAFF spectrum (Step 32) of 31 ksi (213.7 MPa) and testing was discontinued with no failure after 11,285 flights. Specimen 1F40 was cycled at a reference stress of 34 ksi (234.4 MPa) and failed at 9728 flights. The latter reference stress was then approved by the Project Monitor for use on the remaining five fatigue specimens. A summary of the fatigue test data is presented in Table I and detailed data sheets are included in Appendix I. Examples of typical failure surfaces are shown in Figures 3 and 4. In all cases, fatigue failures initiated at the open hole near the sheet midthickness.

Tensile Test Program

Tensile coupons provided by Metcut were tested in the Mechanical Test Laboratory on August 4, 1977. Tests were conducted in a Baldwin 60,000-pound-(266,890 N) capacity Universal test machine. Room temperature was 69 degrees F (21°C) and the relative humidity was 60 percent. The loading rate was controlled at 100 ksi/min (689.5 MPa/min). The results of the tensile tests are presented in Table II.

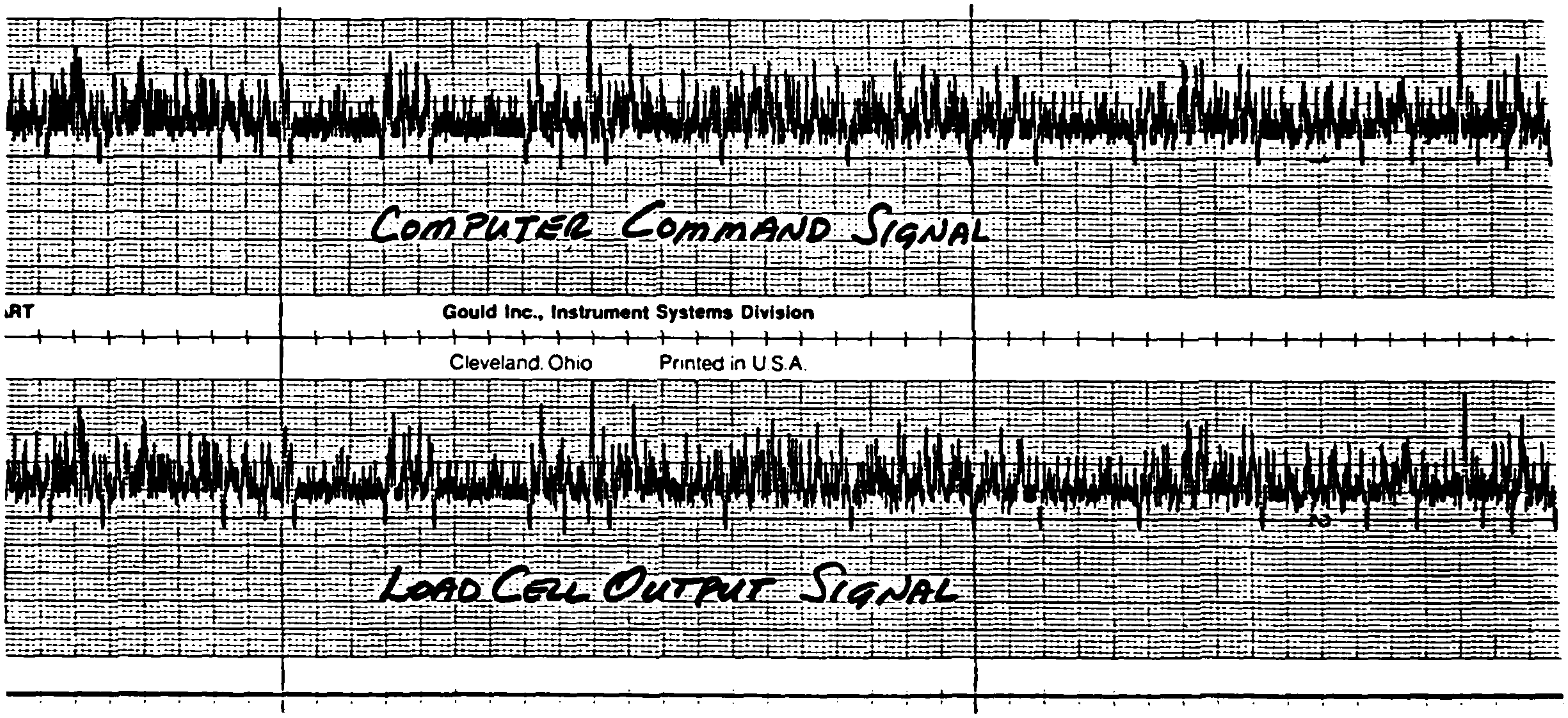


FIGURE 2. COMPUTER COMMAND AND LOAD CELL SIGNAL COMPARISON FOR A PORTION OF THE TEST ON SPECIMEN 1F40

TABLE I. FATIGUE TEST RESULTS*

Specimen Number	Flights to Initial Crack	Initial Crack Size, inch (mm)	Flights to Failure
1F40	9128	0.05 (1.27)	9728
1F23	--	--	9373
1F64	--	--	8824
1F77	9297	0.03 (0.76)	9572
1F85	9835	0.02 (0.51)	10929
1F10	--	--	8364
Mean Life			9465
Standard Deviation			878

* FALSTAFF reference stress - 34 ksi (234.4 MPa).

TABLE II. TENSILE TEST RESULTS

Specimen Number	Yield Strength, ksi (MPa)	Ultimate Strength, ksi (MPa)	Elongation, percent (2-inch gage)
1T24	80.79 (557.0)	84.40 (581.9)	11.5
1T30	80.60 (555.7)	84.34 (581.5)	11.5
1T19	80.22 (553.1)	84.15 (580.2)	11.0
Average	80.54 (555.3)	84.30 (581.2)	11.33
Standard Deviation	.29	.13	.29

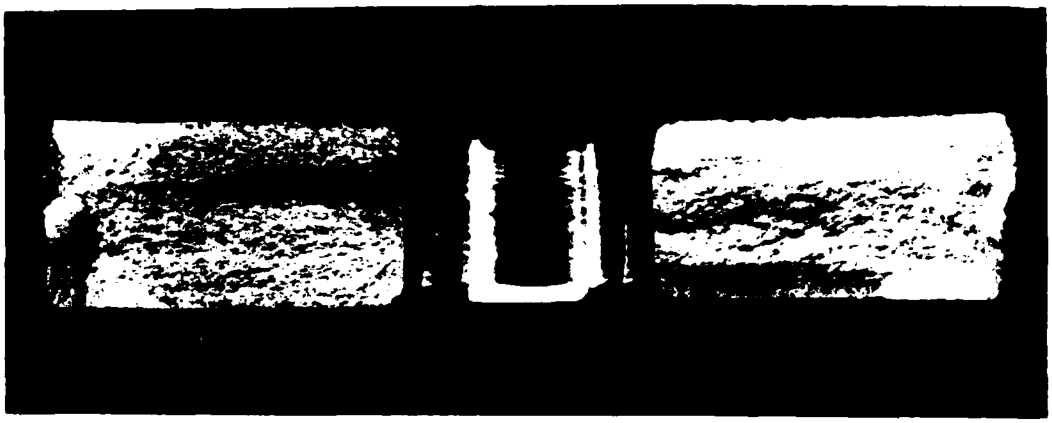


FIGURE 3. FAILURE SURFACE OF SPECIMEN 1F64

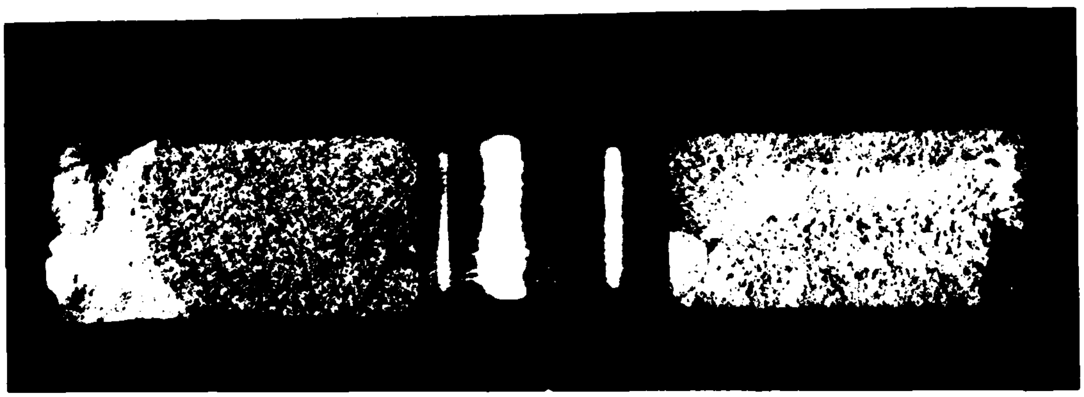


FIGURE 4. FAILURE SURFACE OF SPECIMEN 1F10

SUMMARY AND CONCLUSIONS

Because of the care taken to insure that the FALSTAFF spectrum had been carefully reproduced and continuous checks made during the set-up procedure, it is believed that the fatigue data are truly representative of the lives that can be expected for this test condition. This is confirmed by the low standard deviation for the data (well within normally obtained values). It is expected that the Phase II results will yield results of similar quality. As a result of this phase, all participating nations should be encouraged to continue with Phase II of the program.

APPENDIX I

DATA SHEET

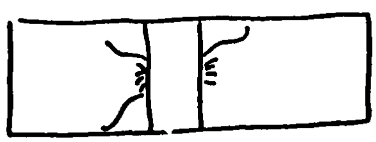
AIR FORCE/AFML - METCUT RESEARCH SPONSORED
AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: BATTELLE'S COLUMBUS LABORATORIES
STRUCTURAL MATERIALS AND TRIBOLOGY SECTION
STRUCTURAL FATIGUE LABORATORY

1. Date of Test: Start 7/12/77 End 7-14-77
2. Manufacture/Model of Fatigue Test Machine: MTS 20KIP
3. Test Temperature: 68 °F (20 ~~23.4~~ °C)
4. Relative Humidity: 56 (%)
5. Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)

   34 ksi (234.4 MPa)
6. Specimen Identification: 1-F-40
7. Specimen Bending at Minimum Load: NONE %
8. Specimen Bending at RMS Mean Load: 1.45 %
9. RMS Mean Cyclic Frequency: 10.5 Hz
10. Number of Flights to Initial Visible Crack: 9128 Flights
11. Size of Initial Visible Crack: .05 (Page 21 in. (1.27 mm)
12. Number of Flights to Catastrophic Failure: 9728 Flights
13. Fatigue-Crack-Initiation Site: IN HOLE AT MID THICKNESS

    - BOTH SIDES



Sketch

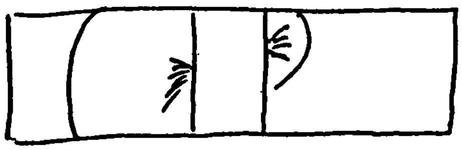
14. Description of Abnormalities:
15. Description of Buckling Restraint (If Used): NONE

DATA SHEET

AIR FORCE/AFML - METCUT RESEARCH SPONSORED
AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: BATTELLE'S COLUMBUS LABORATORIES
STRUCTURAL MATERIALS AND TRIBOLOGY SECTION
STRUCTURAL FATIGUE LABORATORY

1. Date of Test: Start 7-14-77 End 7/16/77
2. Manufacture/Model of Fatigue Test Machine: MTS, 20 KIP
3. Test Temperature: 68 °F (20 °C)
4. Relative Humidity: 55 (%)
5. Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)
   34 ksi (234.4 MPa)
6. Specimen Identification: 1F23
7. Specimen Bending at Minimum Load: NONE %
8. Specimen Bending at RMS Mean Load: 1.45 %
9. RMS Mean Cyclic Frequency: 10.5 Hz
10. Number of Flights to Initial Visible Crack: — Flights
11. Size of Initial Visible Crack: — in. (mm)
12. Number of Flights to Catastrophic Failure: 9373 Flights
13. Fatigue-Crack-Initiation Site: IN HOLE NEAR MID THICKNESS



Sketch

14. Description of Abnormalities:
15. Description of Buckling Restraint (If Used):

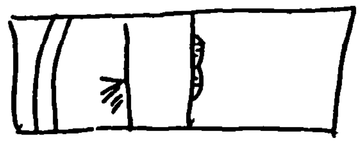
DATA SHEET

AIR FORCE/AFML - METCUT RESEARCH SPONSORED
AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: BATTELLE'S COLUMBUS LABORATORIES
STRUCTURAL MATERIALS AND TRIBOLOGY SECTION
STRUCTURAL FATIGUE LABORATORY

1. Date of Test: Start 7/18/76 End 7/20/76
2. Manufacture/Model of Fatigue Test Machine: MTS 20KIP
3. Test Temperature: 68 °F (20 °C)
4. Relative Humidity: 55 (%)
5. Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)

   34 ksi (234.4 MPa)
6. Specimen Identification: 1F64
7. Specimen Bending at Minimum Load: NONE %
8. Specimen Bending at RMS Mean Load: 1.45 %
9. RMS Mean Cyclic Frequency: 10.5 Hz
10. Number of Flights to Initial Visible Crack: — Flights
11. Size of Initial Visible Crack: — in. (mm)
12. Number of Flights to Catastrophic Failure: 8824 Flights
13. Fatigue-Crack-Initiation Site: IN HOLE NEAR MID THICKNESS



Sketch

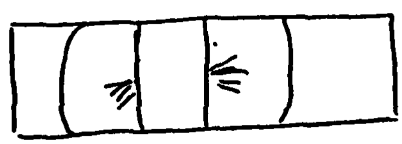
14. Description of Abnormalities:
15. Description of Buckling Restraint (If Used): NONE

DATA SHEET

AIR FORCE/AFML - METCUT RESEARCH SPONSORED
AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: BATTELLE'S COLUMBUS LABORATORIES
STRUCTURAL MATERIALS AND TRIBOLOGY SECTION
STRUCTURAL FATIGUE LABORATORY

1. Date of Test: Start 7/20/77 End 7/22/77
2. Manufacture/Model of Fatigue Test Machine: M.T.S. 20 KIP
3. Test Temperature: 68° °F (20 °C)
4. Relative Humidity: 55 (%)
5. Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)
   34 ksi (234.4 MPa)
6. Specimen Identification: 1F77
7. Specimen Bending at Minimum Load: NONE %
8. Specimen Bending at RMS Mean Load: 1.45 %
9. RMS Mean Cyclic Frequency: 10.5 Hz
10. Number of Flights to Initial Visible Crack: 9297 Flights
11. Size of Initial Visible Crack: 0.03 in. (0.76 mm)
12. Number of Flights to Catastrophic Failure: 9572 Flights
13. Fatigue-Crack-Initiation Site: IN HOLE NEAR MID THICKNESS



Sketch

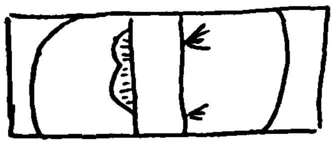
14. *Description of Abnormalities:*
15. Description of Buckling Restraint (If Used): NONE

DATA SHEET

AIR FORCE/AFML - METCUT RESEARCH SPONSORED
AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: BATTELLE'S COLUMBUS LABORATORIES
STRUCTURAL MATERIALS AND TRIBOLOGY SECTION
STRUCTURAL FATIGUE LABORATORY

1. Date of Test: Start 7/27/77 End 7/29/77
2. Manufacture/Model of Fatigue Test Machine: MTS 20 KIPS
3. Test Temperature: 68° °F (20 °C)
4. Relative Humidity: 55 (%)
5. Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)
34 ksi (234.4 MPa)
6. Specimen Identification: 1F85
7. Specimen Bending at Minimum Load: NONE %
8. Specimen Bending at RMS Mean Load: 1.45 %
9. RMS Mean Cyclic Frequency: 10.5 Hz
10. Number of Flights to Initial Visible Crack: 9835 Flights
11. Size of Initial Visible Crack: .020 in. (0.51 mm)
12. Number of Flights to Catastrophic Failure: 10929 Flights
13. Fatigue-Crack-Initiation Site: IN HOLE NEAR MIDTHICKNESS



Sketch

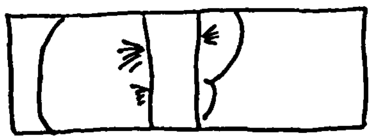
14. Description of Abnormalities:
15. Description of Buckling Restraint (If Used): NONE

DATA SHEET

AIR FORCE/AFML - METCUT RESEARCH SPONSORED
AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: BATTELLE'S COLUMBUS LABORATORIES
STRUCTURAL MATERIALS AND TRIBOLOGY SECTION
STRUCTURAL FATIGUE LABORATORY

1. Date of Test: Start 7-30-77 End 8-1-77
2. Manufacture/Model of Fatigue Test Machine: M.T.S. 20 KIP
3. Test Temperature: 68 °F (20 °C)
4. Relative Humidity: 56 (%)
5. Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)
   34 ksi (234.4 MPa)
6. Specimen Identification: 1-F-10
7. Specimen Bending at Minimum Load: NONE %
8. Specimen Bending at RMS Mean Load: 1.45 %
9. RMS Mean Cyclic Frequency: 10.5 Hz
10. Number of Flights to Initial Visible Crack: —— Flights
11. Size of Initial Visible Crack: —— in. (mm)
12. Number of Flights to Catastrophic Failure: 8,364 Flights
13. Fatigue-Crack-Initiation Site: IN HOLE NEAR MIDTHICKNESS



Sketch

14. Description of Abnormalities:
15. Description of Buckling Restraint (If Used): NONE

A P P E N D I X   D

CRITICALLY LOADED HOLE TECHNOLOGY PILOT PROGRAM

PHASE II REPORT FOR PERIOD APRIL 1978 - AUGUST 1978

BATTELLE
COLUMBUS LABORATORIES
505 KING AVENUE
COLUMBUS, OHIO 43201

August 1978

METCUT RESEARCH ASSOCIATES, INC. PURCHASE ORDER NO. 63654

INTRODUCTION

A pilot program has been initiated by the AGARD SMP Subcommittee on Critically Loaded Hole Technology in an effort to promote a mutual confidence in fatigue test data generated by participating countries. The successful completion of the program will lead to a more uniform quality of fatigue testing and evaluation of critically loaded hole parameters among its participants. The objectives of the three-phase program are as follow:

- Phase I - Generate baseline, open hole, fatigue data in order to examine laboratory-to-laboratory variations
- Phase II - Reaffirm the exchangeability of baseline data and investigate the effect of hole quality on open hole fatigue specimens
- Phase III - Conduct independent fatigue evaluations of various fatigue-improvement fasteners and exchange data.

Participants in the program included representatives from Belgium, France, Germany, Italy, Netherlands, Sweden, United Kingdom, and the United States. All specimens for the program are to be prepared by Metcut Research Associates, Inc., from a single heat of 7050 material procured from Alcoa in the form of 7050-T76 bare sheet, 0.196-inch (5 mm) thick. Battelle's Columbus Laboratories (BCL) has been designated as the USA testing facility.

The report contained herein details the results of the Phase II effort.

GENERATION OF THE FALSTAFF SPECTRUM

In order to insure that all participants apply the same cyclic loads, each country was to test specimens under the FALSTAFF (Fighter Aircraft Loading STAndard For Fatigue). The BCL fatigue load control program was generated using the computer program detailed in the definitive description of the FALSTAFF spectrum, dated March 1976. The details of the BCL load control program generation were presented in the Phase I report dated February 1978.

PROGRAM CONTROL

This section describes the BCL system and equipment used to apply and control FALSTAFF program loads. In general, the HP 2100 computer provides load steps to a hybrid unit which generates a constant ramp rate function for the MTS 20,000-pound (88,960 N) closed-loop electrohydraulic fatigue machine. A null pacing unit makes a constant comparison of programmed load-to-load cell output and signals the hybrid unit when the programmed load has been reached, at which time the ramp direction is reversed and a new load is called from the computer. This procedure continues until a preprogrammed number of flights has been reached or until the test specimen fails. A graphic presentation of the program control cycle is presented in Figure 1. A secondary computer subroutine, STATS, makes it possible to determine the flight number, total number of cycles, and percent of a pass through the spectrum completed at the moment of questioning.

Pretest Checks

Prior to initiating the fatigue test program, pretest checks were made (as in Phase I) using the Phase I spare specimen (without a hole in the test section) instrumented with two strain gages located near the specimen edge on each face of the specimen. The output of the four strain gages made it possible to determine specimen bending and buckling (if any existed) and to confirm that dynamic loads matched static calibration loads.

Bending Check

Strain gage data were obtained at incremental load steps for loads to an equivalent of 38 ksi (262 MPa) maximum and -19 ksi (131 MPa) minimum. Data were obtained for three loading cycles. The strain-load data were submitted to a linear regression analysis with resulting R^2 statistic values ranging from 1.000 to .9994. Strain values were computed for the load equivalent of 30 ksi (206.85 MPa) gross stress. Analysis of the strain values indicated that the maximum error due to specimen bending was 2.53 percent. Analysis of the compressive load data indicated that no buckling could be detected.

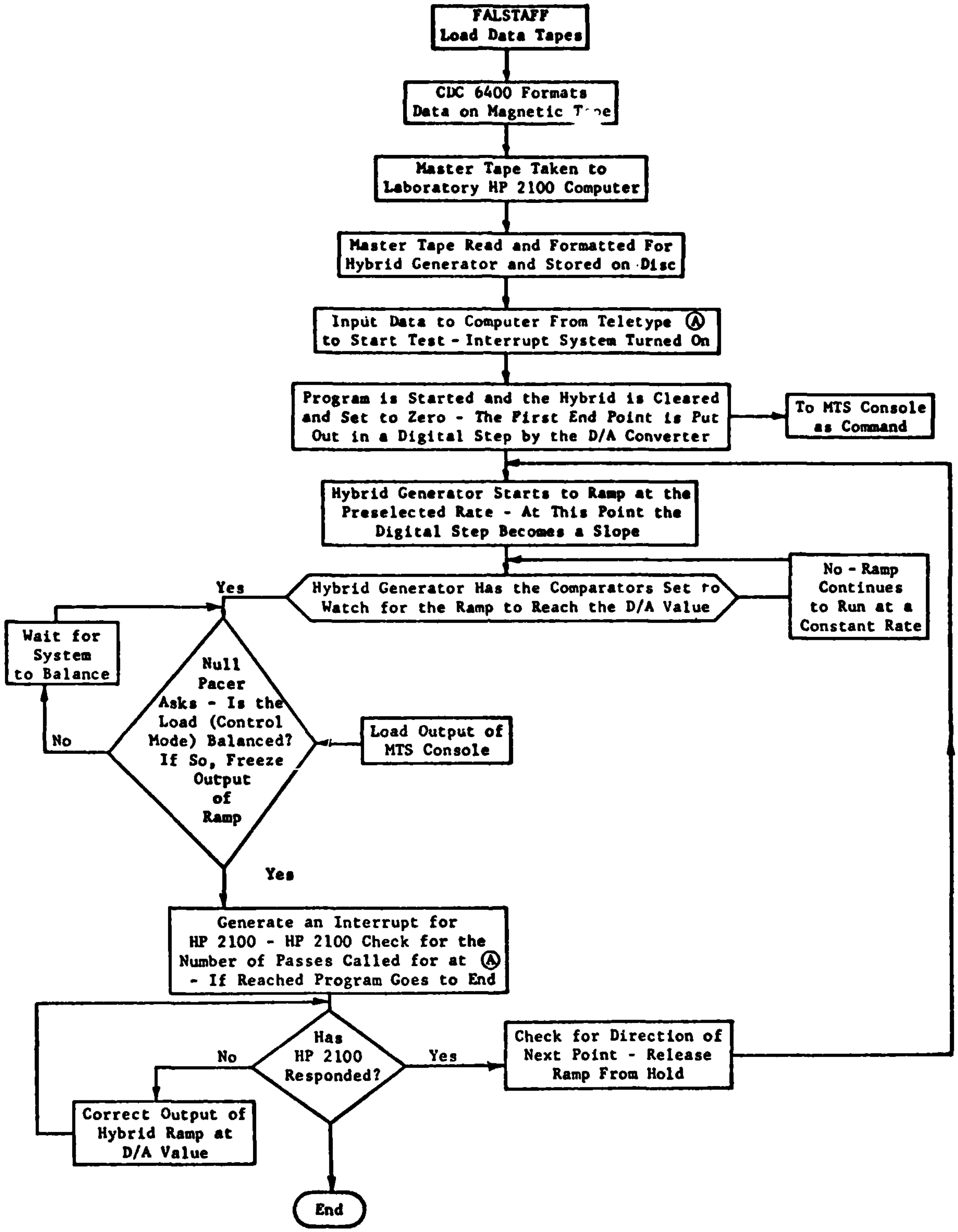


FIGURE 1. PROGRAM CONTROL CYCLE

Static-Dynamic Loads Check

Comparison of strain gage output and calibrated load cell output indicated a maximum axial load error of 2.30 percent at 38 ksi (262 MPa) static load. Application of cyclic loads at the same level provided the same strain outputs at frequencies of 1, 5, and 10 Hz.

FALSTAFF Loads Check

The specimen was subjected to FALSTAFF loads cycling and ramp rate and MTS unit controls were adjusted so that fatigue machine load output matched the command signal (reference Figure 2). In addition, records were made of computer command signal versus dummy specimen strain level (reference Figure 3) and command signal versus load cell output over expanded time scale (reference Figure 4). Note that Figure 4 shows the time lag (0.0008 to 0.0020 seconds) required to extract the next load command from the computer. The controls were not changed during the rest of the test program and the mean cyclic rate was determined to be 10.5 Hz.

TEST RESULTS

Fatigue Test Program

Fatigue test specimens, as supplied by Metcut Research Associates, Inc., were selected at random from all three specimen types (Phase I Report, high and low quality holes). All specimens were cycled at a reference stress of 34 ksi (234.4 MPa). A summary of the fatigue test data is presented in Table I and detailed data sheets are included in Appendix I. Macrographs of failure surfaces are shown in Appendix II.

NOTE: The data for the High Quality Hole Specimen BF-179, which failed at 15,176 flights, is not tabulated because it was determined that the programmed reference load was set approximately 20 percent of the required level of 34 ksi (234.4 MPa).

TABLE I. FATIGUE TEST RESULTS*

Specimen Number		Flights to Failure
	PHASE I REPEAT	
AF-26		8.172
BF-242		6,680
BF-235		6,359
BF-224		7,729
AF-45		6,831
AF-47		6,831
	Mean Life	7,100
	Standard Deviation	695
	HIGH-QUALITY HOLES	
BF-227		8,129
AF-122		8,392
BF-281		9,572
AF-78		5,231
AF-136		10,324
	Mean Life	8,330
	Standard Deviation	1,947
	LOW-QUALITY HOLES	
BF-305		9,329
BF-323		5,372
BF-228		6,631
AF-123		6,224
AF-88		5,372
AF-43		7,431
AF-138		6,831
AF-114		4,972
BF-223		6,877
AF-112		5,431
	Mean Life	6,447
	Standard Deviation	1,300

* FALSTAFF reference stress - 34 ksi (234.4 MPa)

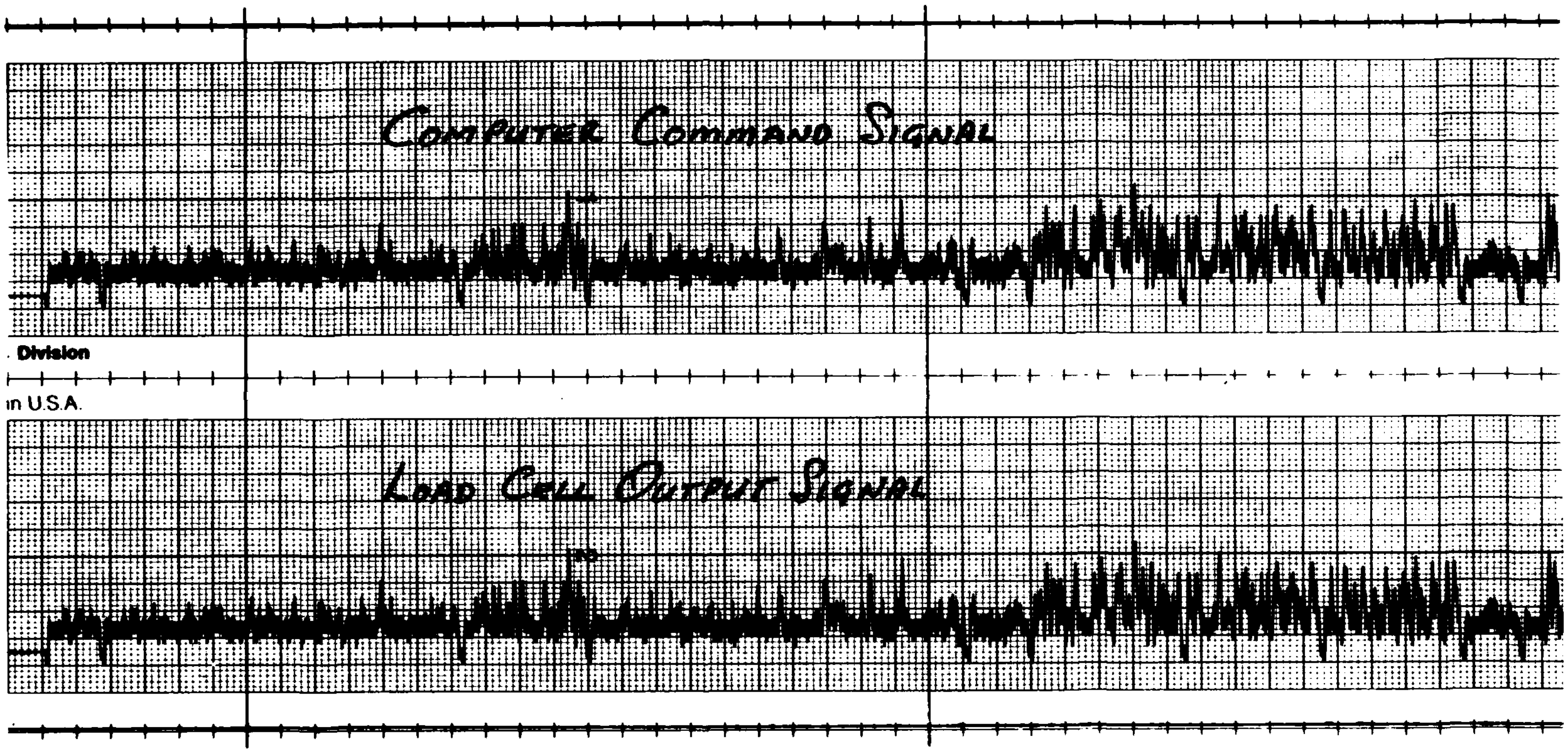


FIGURE 2. COMPUTER COMMAND AND LOAD CELL SIGNAL COMPARISON FOR A PORTION OF THE TEST ON SPECIMEN AF-26

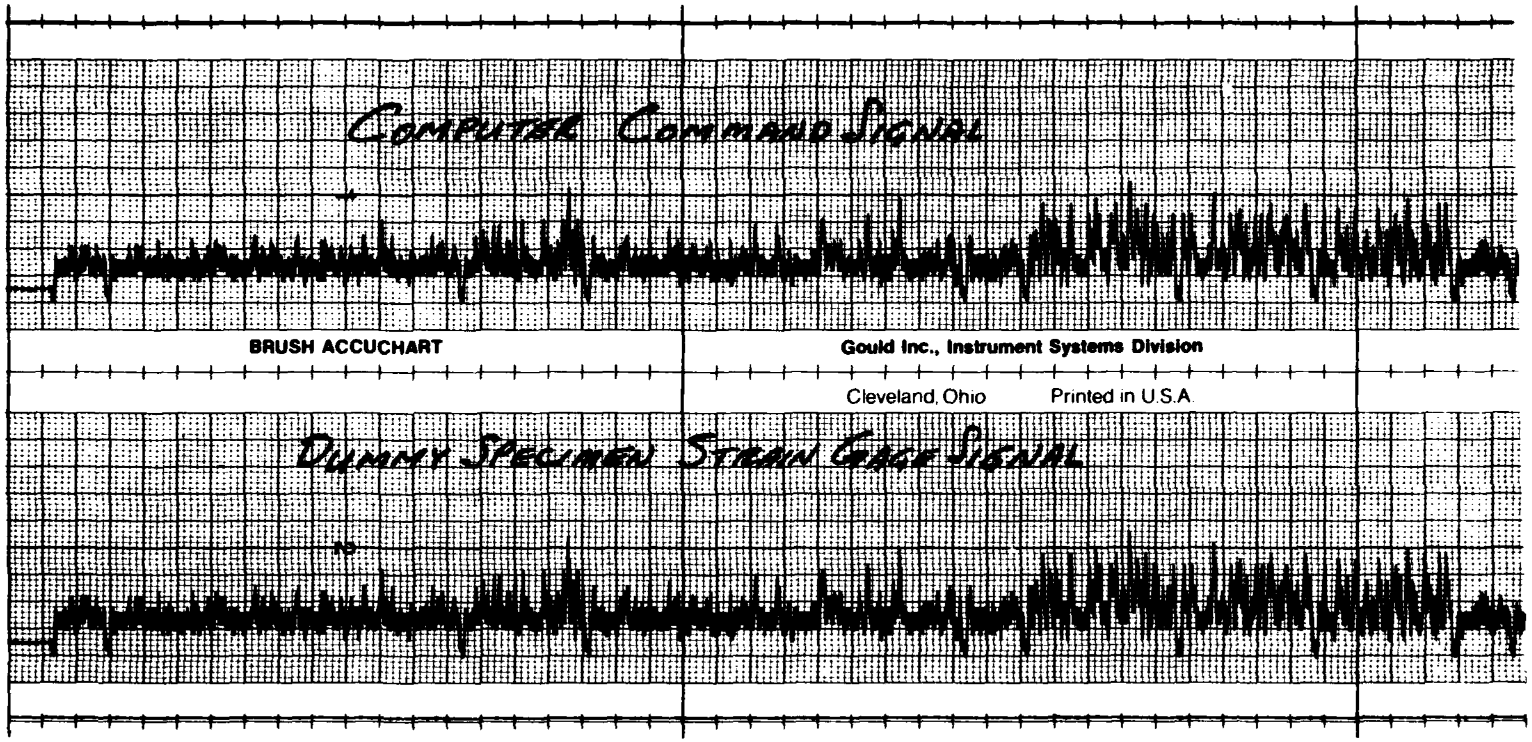


FIGURE 3. COMPUTER COMMAND AND DUMMY SPECIMEN STRAIN GAGE SIGNAL FOR A PORTION OF THE FALSTAFF SPECTRUM

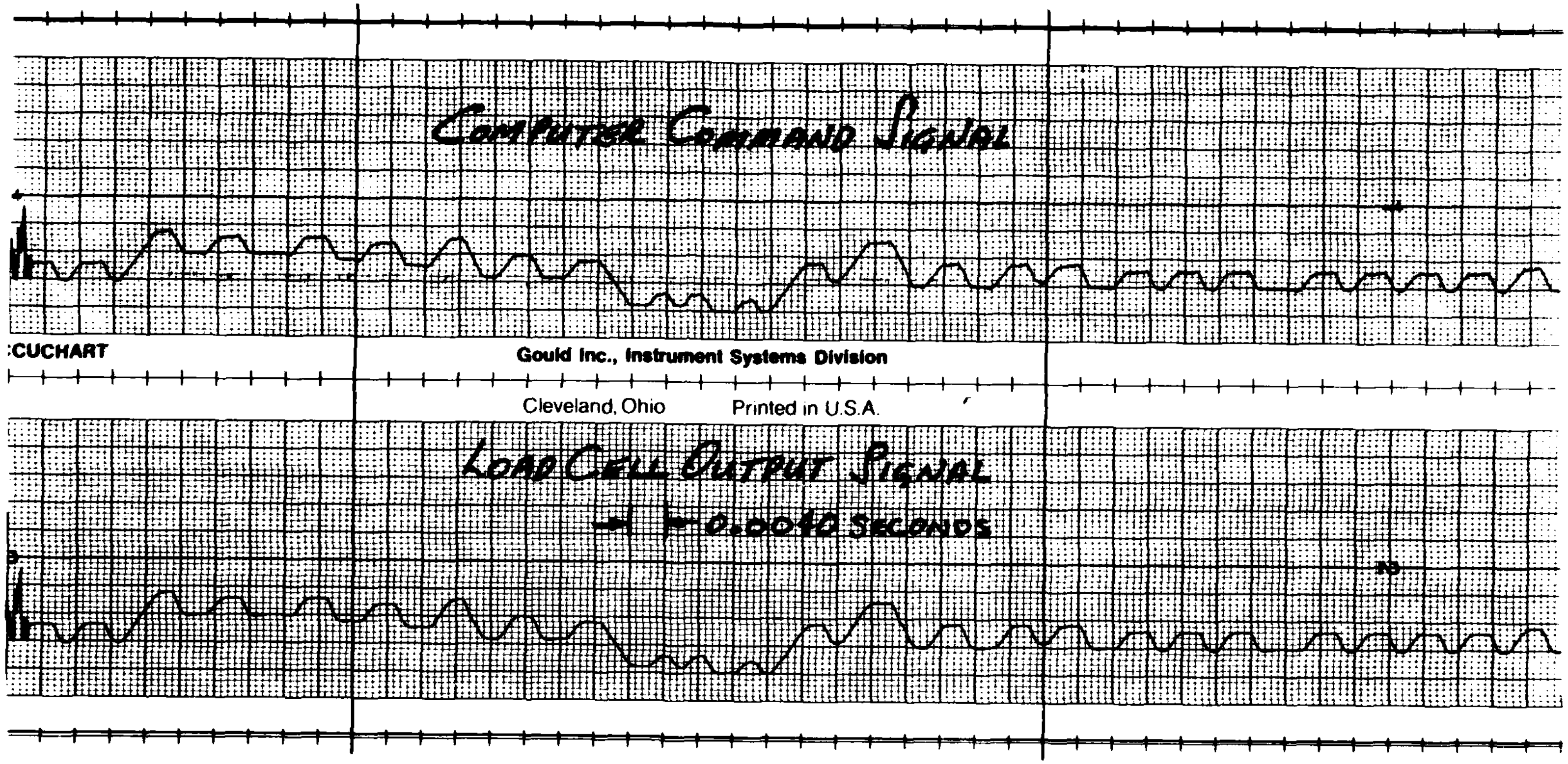


FIGURE 4. EXPANDED TIME SCALE COMPARISON OF COMPUTER COMMAND AND LOAD CELL OUTPUT SIGNALS FOR A PORTION OF THE FALSTAFF SPECTRUM

APPENDIX I

DETAILED DATA SHEETS

DATA SHEET

AIR FORCE/AFML - METCUT RESEARCH SPONSORED
AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: BATTELLE'S COLUMBUS LABORATORIES
STRUCTURAL MATERIALS AND TRIBOLOGY SECTION
STRUCTURAL FATIGUE LABORATORY

1. Date of Test: Start 6-8-78 End 6-9-78
2. Manufacture/Model of Fatigue Test Machine: MTS 20KIP
3. Test Temperature: 68 °F (20 °C)
4. Relative Humidity: 56 (%)
5. Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)
   34 ksi (234.4 MPa)
6. Specimen Identification: AF-26
7. Specimen Bending at Minimum Load: NONE %
8. Specimen Bending at RMS Mean Load: 2.53 %
9. RMS Mean Cyclic Frequency: 10.5 Hz
10. Number of Flights to Initial Visible Crack: ~~8172~~ N.A. Flights
11. Size of Initial Visible Crack: N.A. in. (mm)
12. Number of Flights to Catastrophic Failure: 8172 Flights
13. Fatigue-Crack-Initiation Site:

SEE PHOTO

Sketch

14. Description of Abnormalities: NONE
15. Description of Buckling Restraint (If Used):

DATA SHEET

AIR FORCE/AFML - METCUT RESEARCH SPONSORED
AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: BATTELLE'S COLUMBUS LABORATORIES
STRUCTURAL MATERIALS AND TRIBOLOGY SECTION
STRUCTURAL FATIGUE LABORATORY

1. Date of Test: Start 6-13-78 End 6-14-78
2. Manufacture/Model of Fatigue Test Machine: MTS 50 KIP
3. Test Temperature: 65 °F (20 °C)
4. Relative Humidity: 55 (%)
5. Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)

   54 ksi (254.4 MPa)
6. Specimen Identification: BF 305
7. Specimen Bending at Minimum Load: None %
8. Specimen Bending at RMS Mean Load: 2.53 %
9. RMS Mean Cyclic Frequency: 10.5 Hz
10. Number of Flights to Initial Visible Crack: N/A Flights
11. Size of Initial Visible Crack: N/A in. (____ mm)
12. Number of Flights to Catastrophic Failure: 7329 Flights
13. Fatigue-Crack-Initiation Site: ____

See Photo

Sketch

14. Description of Abnormalities: NONE
15. Description of Buckling Restraint (If Used): ____

DATA SHEET

AIR FORCE/AFML - METCUT RESEARCH SPONSORED
AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: BATTELLE'S COLUMBUS LABORATORIES
STRUCTURAL MATERIALS AND TRIBOLOGY SECTION
STRUCTURAL FATIGUE LABORATORY

1. Date of Test: Start 5-14-78 End 5-15-78
2. Manufacture/Model of Fatigue Test Machine: MTS 20 KIP
3. Test Temperature: 68 °F (°C)
4. Relative Humidity: 55 (%)
5. Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)
   54 ksi (334.4 MPa)
6. Specimen Identification: BF 227
7. Specimen Bending at Minimum Load: None %
8. Specimen Bending at RMS Mean Load: 0.5.3 %
9. RMS Mean Cyclic Frequency: 1.5 Hz
10. Number of Flights to Initial Visible Crack: NA Flights
11. Size of Initial Visible Crack: NA in. (mm)
12. Number of Flights to Catastrophic Failure: 8124 Flights
13. Fatigue-Crack-Initiation Site:

see Photo Sketch

14. Description of Abnormalities: NONE
15. Description of Buckling Restraint (If Used):

DATA SHEET

AIR FORCE/AFML - METCUT RESEARCH SPONSORED
AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: BATTELLE'S COLUMBUS LABORATORIES
STRUCTURAL MATERIALS AND TRIBOLOGY SECTION
STRUCTURAL FATIGUE LABORATORY

1. Date of Test: Start 6-15-78 End 6-16-78
2. Manufacture/Model of Fatigue Test Machine: MTS 20K III
3. Test Temperature: 68 °F (20 °C)
4. Relative Humidity: 55 (%)
5. Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)

   34 ksi (234.4 MPa)
6. Specimen Identification: AF-323
7. Specimen Bending at Minimum Load: None %
8. Specimen Bending at RMS Mean Load: 2.53 %
9. RMS Mean Cyclic Frequency: 10.5 Hz
10. Number of Flights to Initial Visible Crack: NA Flights
11. Size of Initial Visible Crack: NA in. (____ mm)
12. Number of Flights to Catastrophic Failure: 5372 Flights
13. Fatigue-Crack-Initiation Site:

    see photo

    Sketch
14. Description of Abnormalities: None
15. Description of Buckling Restraint (If Used):

DATA SHEET

AIR FORCE/AFML - METCUT RESEARCH SPONSORED
AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: BATTELLE'S COLUMBUS LABORATORIES
STRUCTURAL MATERIALS AND TRIBOLOGY SECTION
STRUCTURAL FATIGUE LABORATORY

1. Date of Test: Start 5-16-78 End 6-17-78
2. Manufacture/Model of Fatigue Test Machine: MTS 20 Kip
3. Test Temperature: 68 °F (20 °C)
4. Relative Humidity: 55 (%)
5. Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)
   34 ksi (234.4 MPa)
6. Specimen Identification: DF-88
7. Specimen Bending at Minimum Load: None %
8. Specimen Bending at RMS Mean Load: 2.3 %
9. RMS Mean Cyclic Frequency: 10.5 Hz
10. Number of Flights to Initial Visible Crack: ~~5372~~ N/A Flights
11. Size of Initial Visible Crack: N/A in. (mm)
12. Number of Flights to Catastrophic Failure: 5372 Flights
13. Fatigue-Crack-Initiation Site:

See Photo Sketch

14. Description of Abnormalities: None
15. Description of Buckling Restraint (If Used):

DATA SHEET

AIR FORCE/AFML - METCUT RESEARCH SPONSORED
AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: BATTELLE'S COLUMBUS LABORATORIES
STRUCTURAL MATERIALS AND TRIBOLOGY SECTION
STRUCTURAL FATIGUE LABORATORY

1. Date of Test: Start 6-19-78 End 6-26-78
2. Manufacture/Model of Fatigue Test Machine: MTS 20 KIP
3. Test Temperature: 68 °F (20 °C)
4. Relative Humidity: 55 (%)
5. Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)

   34 ksi (234.4 MPa)
6. Specimen Identification: NF-122
7. Specimen Bending at Minimum Load: None %
8. Specimen Bending at RMS Mean Load: 25.3 %
9. RMS Mean Cyclic Frequency: 10.5 Hz
10. Number of Flights to Initial Visible Crack: 2114 Flights
11. Size of Initial Visible Crack: .114 in. (______ mm)
12. Number of Flights to Catastrophic Failure: 5592 Flights
13. Fatigue-Crack-Initiation Site: ______

See Photo Sketch

14. Description of Abnormalities: None.
15. Description of Buckling Restraint (If Used): ______

DATA SHEET

AIR FORCE/AFML - METCUT RESEARCH SPONSORED
AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: BATTELLE'S COLUMBUS LABORATORIES
STRUCTURAL MATERIALS AND TRIBOLOGY SECTION
STRUCTURAL FATIGUE LABORATORY

1. Date of Test: Start 6-21-78 End 6-22-78
2. Manufacture/Model of Fatigue Test Machine: MTS - 20 KIP
3. Test Temperature: 68 °F (20 °C)
4. Relative Humidity: 55 (%)
5. Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)
   34 ksi (234.4 MPa)
6. Specimen Identification: BF-228
7. Specimen Bending at Minimum Load: NONE %
8. Specimen Bending at RMS Mean Load: 2.53 %
9. RMS Mean Cyclic Frequency: 10.5 Hz
10. Number of Flights to Initial Visible Crack: NA Flights
11. Size of Initial Visible Crack: NA in. (mm)
12. Number of Flights to Catastrophic Failure: 6631 Flights
13. Fatigue-Crack-Initiation Site:

SEE PHOTO

Sketch

14. Description of Abnormalities: NONE
15. Description of Buckling Restraint (If Used):

DATA SHEET

AIR FORCE/AFML - METCUT RESEARCH SPONSORED
AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: **BATTELLE'S COLUMBUS LABORATORIES**
STRUCTURAL MATERIALS AND TRIBOLOGY SECTION
STRUCTURAL FATIGUE LABORATORY

1. **Date of Test: Start** 6-22-78 **End** 6-23-78
2. **Manufacture/Model of Fatigue Test Machine:** MTS 20 Kip
3. **Test Temperature:** 68 **°F** (20 **°C)**
4. **Relative Humidity:** 55 **(%)**
5. **Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)**
   34 **ksi** (234.4 **MPa)**
6. **Specimen Identification:** AF-123
7. **Specimen Bending at Minimum Load:** none **%**
8. **Specimen Bending at RMS Mean Load:** 0.53 **%**
9. **RMS Mean Cyclic Frequency:** 10.5 **Hz**
10. **Number of Flights to Initial Visible Crack:** 1114 **Flights**
11. **Size of Initial Visible Crack:** 0.14 **in.** (**mm)**
12. **Number of Flights to Catastrophic Failure:** 6024 **Flights**
13. **Fatigue-Crack-Initiation Site:**

See Photo **Sketch**

14. **Description of Abnormalities:** None
15. **Description of Buckling Restraint (If Used):**

DATA SHEET

AIR FORCE/AFML - METCUT RESEARCH SPONSORED
AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: BATTELLE'S COLUMBUS LABORATORIES
STRUCTURAL MATERIALS AND TRIBOLOGY SECTION
STRUCTURAL FATIGUE LABORATORY

1. Date of Test: Start 6-26-78 End 6-27-78
2. Manufacture/Model of Fatigue Test Machine: MTS 20 KIP
3. Test Temperature: 68 °F (20 °C)
4. Relative Humidity: 55 (%)
5. Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)
   34 ksi (234.4 MPa)
6. Specimen Identification: BF-242
7. Specimen Bending at Minimum Load: None %
8. Specimen Bending at RMS Mean Load: 2.53 %
9. RMS Mean Cyclic Frequency: 15.5 Hz
10. Number of Flights to Initial Visible Crack: N/A Flights
11. Size of Initial Visible Crack: N/A in. (mm)
12. Number of Flights to Catastrophic Failure: 2080 Flights
13. Fatigue-Crack-Initiation Site:

See photo

Sketch

14. Description of Abnormalities: None
15. Description of Buckling Restraint (If Used):

DATA SHEET

AIR FORCE/AFML - METCUT RESEARCH SPONSORED
AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: BATTELLE'S COLUMBUS LABORATORIES
STRUCTURAL MATERIALS AND TRIBOLOGY SECTION
STRUCTURAL FATIGUE LABORATORY

1. Date of Test: Start 6-27-78 End 6-28-78
2. Manufacture/Model of Fatigue Test Machine: 20 KIP MTS
3. Test Temperature: 68 °F (20 °C)
4. Relative Humidity: 55 (%)
5. Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)
   34 ksi (234.4 MPa)
6. Specimen Identification: AF-43
7. Specimen Bending at Minimum Load: 0 %
8. Specimen Bending at RMS Mean Load: 2.53 %
9. RMS Mean Cyclic Frequency: 10.5 Hz
10. Number of Flights to Initial Visible Crack: NA Flights
11. Size of Initial Visible Crack: N/A in. (mm)
12. Number of Flights to Catastrophic Failure: 7431 Flights
13. Fatigue-Crack-Initiation Site:

    SEE PHOTO

    Sketch
14. Description of Abnormalities: NONE
15. Description of Buckling Restraint (If Used):

DATA SHEET

AIR FORCE/AFML - METCUT RESEARCH SPONSORED
AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: BATTELLE'S COLUMBUS LABORATORIES
STRUCTURAL MATERIALS AND TRIBOLOGY SECTION
STRUCTURAL FATIGUE LABORATORY

1. Date of Test: Start -28-78 End 6-29-78
2. Manufacture/Model of Fatigue Test Machine: MTS 50 KIP
3. Test Temperature: 75 °F (24 C °C)
4. Relative Humidity: 55 (%)
5. Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)

   34 ksi (234.4 MPa)
6. Specimen Identification: AF-242
7. Specimen Bending at Minimum Load: None %
8. Specimen Bending at RMS Mean Load: 2.53 %
9. RMS Mean Cyclic Frequency: 10.5 Hz
10. Number of Flights to Initial Visible Crack: N/A Flights
11. Size of Initial Visible Crack: N/A in. (mm)
12. Number of Flights to Catastrophic Failure: 6650 Flights
13. Fatigue-Crack-Initiation Site:

See Photo

Sketch

14. Description of Abnormalities: None
15. Description of Buckling Restraint (If Used):

DATA SHEET

AIR FORCE/AFML - METCUT RESEARCH SPONSORED
AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: BATTELLE'S COLUMBUS LABORATORIES
STRUCTURAL MATERIALS AND TRIBOLOGY SECTION
STRUCTURAL FATIGUE LABORATORY

1. Date of Test: Start 6-30-78 End 7-1-78
2. Manufacture/Model of Fatigue Test Machine: MTS [illegible]
3. Test Temperature: 65 °F (18 °C)
4. Relative Humidity: 55 (%)
5. Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)
   34 ksi (234.4 MPa)
6. Specimen Identification: DF-13E
7. Specimen Bending at Minimum Load: None %
8. Specimen Bending at RMS Mean Load: 2.53 %
9. RMS Mean Cyclic Frequency: 10.5 Hz
10. Number of Flights to Initial Visible Crack: 1110 Flights
11. Size of Initial Visible Crack: .117 in. (mm)
12. Number of Flights to Catastrophic Failure: 6531 Flights
13. Fatigue-Crack-Initiation Site:

See Photo

Sketch

14. Description of Abnormalities: None
15. Description of Buckling Restraint (If Used):

DATA SHEET

AIR FORCE/AFML - METCUT RESEARCH SPONSORED
AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: BATTELLE'S COLUMBUS LABORATORIES
STRUCTURAL MATERIALS AND TRIBOLOGY SECTION
STRUCTURAL FATIGUE LABORATORY

1. Date of Test: Start 7-1-78 End 7-2-78
2. Manufacture/Model of Fatigue Test Machine: MTS 20 KIP
3. Test Temperature: 68 °F (20 °C)
4. Relative Humidity: 55 (%)
5. Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)

   34 ksi (234.4 MPa)
6. Specimen Identification: DF-7E
7. Specimen Bending at Minimum Load: None %
8. Specimen Bending at RMS Mean Load: 2.53 %
9. RMS Mean Cyclic Frequency: 12.5 Hz
10. Number of Flights to Initial Visible Crack: NA Flights
11. Size of Initial Visible Crack: NA in. (mm)
12. Number of Flights to Catastrophic Failure: 5231 Flights
13. Fatigue-Crack-Initiation Site:

See Photo

Sketch

14. Description of Abnormalities: None
15. Description of Buckling Restraint (If Used):

DATA SHEET

AIR FORCE/AFML - METCUT RESEARCH SPONSORED
AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: BATTELLE'S COLUMBUS LABORATORIES
STRUCTURAL MATERIALS AND TRIBOLOGY SECTION
STRUCTURAL FATIGUE LABORATORY

1. Date of Test: Start 7-2-78 End 7-3-78
2. Manufacture/Model of Fatigue Test Machine: MTS 50 KIP
3. Test Temperature: 68 °F (20 °C)
4. Relative Humidity: 55 (%)
5. Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)
   34 ksi (234.4 MPa)
6. Specimen Identification: AF-114
7. Specimen Bending at Minimum Load: None %
8. Specimen Bending at RMS Mean Load: 2.53 %
9. RMS Mean Cyclic Frequency: 12.5 Hz
10. Number of Flights to Initial Visible Crack: NA Flights
11. Size of Initial Visible Crack: .14 in. (mm)
12. Number of Flights to Catastrophic Failure: 4772 Flights
13. Fatigue-Crack-Initiation Site:

    See Photo

    Sketch

14. Description of Abnormalities: None
15. Description of Buckling Restraint (If Used):

DATA SHEET

AIR FORCE/AFML - METCUT RESEARCH SPONSORED
AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: BATTELLE'S COLUMBUS LABORATORIES
STRUCTURAL MATERIALS AND TRIBOLOGY SECTION
STRUCTURAL FATIGUE LABORATORY

1. Date of Test: Start 7-3-78 End 7-4-78
2. Manufacture/Model of Fatigue Test Machine: MTS - 50 KIP
3. Test Temperature: 68 °F (20 °C)
4. Relative Humidity: 55 (%)
5. Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)
   34 ksi (234.4 MPa)
6. Specimen Identification: DF-136
7. Specimen Bending at Minimum Load: None %
8. Specimen Bending at RMS Mean Load: 3.53 %
9. RMS Mean Cyclic Frequency: 1.65 Hz
10. Number of Flights to Initial Visible Crack: N/A Flights
11. Size of Initial Visible Crack: N/A in. (mm)
12. Number of Flights to Catastrophic Failure: 10320 Flights
13. Fatigue-Crack-Initiation Site:

See Photo

Sketch

14. Description of Abnormalities: None
15. Description of Buckling Restraint (If Used):

DATA SHEET

AIR FORCE/AFML - METCUT RESEARCH SPONSORED
AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: BATTELLE'S COLUMBUS LABORATORIES
STRUCTURAL MATERIALS AND TRIBOLOGY SECTION
STRUCTURAL FATIGUE LABORATORY

1. **Date of Test: Start** 7-5-78 **End** 7-6-78
2. **Manufacture/Model of Fatigue Test Machine:** MTS 20 KIP
3. **Test Temperature:** 66 °F (20 °C)
4. **Relative Humidity:** 55 (%)
5. **Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)**
   54 ksi (374.4 MPa)
6. **Specimen Identification:** BH-223
7. **Specimen Bending at Minimum Load:** None %
8. **Specimen Bending at RMS Mean Load:** 2.53 %
9. **RMS Mean Cyclic Frequency:** 10.5 Hz
10. **Number of Flights to Initial Visible Crack:** NA Flights
11. **Size of Initial Visible Crack:** NA in. (mm)
12. **Number of Flights to Catastrophic Failure:** 3377 Flights
13. **Fatigue-Crack-Initiation Site:**

See Photo

Sketch

14. **Description of Abnormalities:** None
15. **Description of Buckling Restraint (If Used):**

DATA SHEET

AIR FORCE/AFML - METCUT RESEARCH SPONSORED
AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: BATTELLE'S COLUMBUS LABORATORIES
STRUCTURAL MATERIALS AND TRIBOLOGY SECTION
STRUCTURAL FATIGUE LABORATORY

1. Date of Test: Start 7-7-78 End 7-8-78

2. Manufacture/Model of Fatigue Test Machine: MTS [illegible]

3. Test Temperature: 68 °F (20 °C)

4. Relative Humidity: 55 (%)

5. Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)

34 ksi (234.4 MPa)

6. Specimen Identification: [illegible]

7. Specimen Bending at Minimum Load: [illegible] %

8. Specimen Bending at RMS Mean Load: [illegible] %

9. RMS Mean Cyclic Frequency: [illegible] Hz

10. Number of Flights to Initial Visible Crack: [illegible] Flights

11. Size of Initial Visible Crack: [illegible] in. (mm)

12. Number of Flights to Catastrophic Failure: [illegible] Flights

13. Fatigue-Crack-Initiation Site:

See photo

Sketch

14. Description of Abnormalities: [illegible]

15. Description of Buckling Restraint (If Used):

DATA SHEET

AIR FORCE/AFML - METCUT RESEARCH SPONSORED
AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: BATTELLE'S COLUMBUS LABORATORIES
STRUCTURAL MATERIALS AND TRIBOLOGY SECTION
STRUCTURAL FATIGUE LABORATORY

1. Date of Test: Start 7-10-78 End 7-11-78
2. Manufacture/Model of Fatigue Test Machine: MTS - 20 KIP
3. Test Temperature: 68 °F (20 °C)
4. Relative Humidity: 55 (%)
5. Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)

   34 ksi (234.4 MPa)
6. Specimen Identification: NF-224
7. Specimen Bending at Minimum Load: None %
8. Specimen Bending at RMS Mean Load: 2.53 %
9. RMS Mean Cyclic Frequency: 10.5 Hz
10. Number of Flights to Initial Visible Crack: N/A Flights
11. Size of Initial Visible Crack: N/A in. (mm)
12. Number of Flights to Catastrophic Failure: 7721 Flights
13. Fatigue-Crack-Initiation Site:

See Photo

Sketch

14. Description of Abnormalities: None
15. Description of Buckling Restraint (If Used):

DATA SHEET

AIR FORCE/AFML - METCUT RESEARCH SPONSORED
AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: BATTELLE'S COLUMBUS LABORATORIES
STRUCTURAL MATERIALS AND TRIBOLOGY SECTION
STRUCTURAL FATIGUE LABORATORY

1. Date of Test: Start 7-11-78 End 7-12-78
2. Manufacture/Model of Fatigue Test Machine: MTS 50 Kip
3. Test Temperature: 68 °F (20 °C)
4. Relative Humidity: 55 (%)
5. Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)

   34 ksi (234.4 MPa)
6. Specimen Identification: AF-45
7. Specimen Bending at Minimum Load: None %
8. Specimen Bending at RMS Mean Load: 2.53 %
9. RMS Mean Cyclic Frequency: 20.5 Hz
10. Number of Flights to Initial Visible Crack: N/A Flights
11. Size of Initial Visible Crack: N/A in. (mm)
12. Number of Flights to Catastrophic Failure: 6831 Flights
13. Fatigue-Crack-Initiation Site:

See Photo

Sketch

14. Description of Abnormalities: None
15. Description of Buckling Restraint (If Used):

DATA SHEET

AIR FORCE/AFML - METCUT RESEARCH SPONSORED
AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: BATTELLE'S COLUMBUS LABORATORIES
STRUCTURAL MATERIALS AND TRIBOLOGY SECTION
STRUCTURAL FATIGUE LABORATORY

1. Date of Test: Start 7-12-78 End 7-13-78
2. Manufacture/Model of Fatigue Test Machine: MTS 20 KIP
3. Test Temperature: 68 °F (20 °C)
4. Relative Humidity: 55 (%)
5. Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)
   34 ksi (234.4 MPa)
6. Specimen Identification: AF-112
7. Specimen Bending at Minimum Load: None %
8. Specimen Bending at RMS Mean Load: 0.58 %
9. RMS Mean Cyclic Frequency: 10.5 Hz
10. Number of Flights to Initial Visible Crack: 2111 Flights
11. Size of Initial Visible Crack: 1/16 in. (mm)
12. Number of Flights to Catastrophic Failure: 5431 Flights
13. Fatigue-Crack-Initiation Site:

See Photo

Sketch

14. Description of Abnormalities: None.
15. Description of Buckling Restraint (If Used):

DATA SHEET

AIR FORCE/AFML - METCUT RESEARCH SPONSORED
AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: BATTELLE'S COLUMBUS LABORATORIES
STRUCTURAL MATERIALS AND TRIBOLOGY SECTION
STRUCTURAL FATIGUE LABORATORY

1. Date of Test: Start 7-13-78 End 7-14-78
2. Manufacture/Model of Fatigue Test Machine: MTS 20 KIP
3. Test Temperature: 68 °F (20 °C)
4. Relative Humidity: 55 (%)
5. Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)
   34 ksi (234.4 MPa)
6. Specimen Identification: 11F-47
7. Specimen Bending at Minimum Load: None %
8. Specimen Bending at RMS Mean Load: 2.53 %
9. RMS Mean Cyclic Frequency: 10.5 Hz
10. Number of Flights to Initial Visible Crack: N/A Flights
11. Size of Initial Visible Crack: N/A in. (mm)
12. Number of Flights to Catastrophic Failure: 6831 Flights
13. Fatigue-Crack-Initiation Site:

See Photo

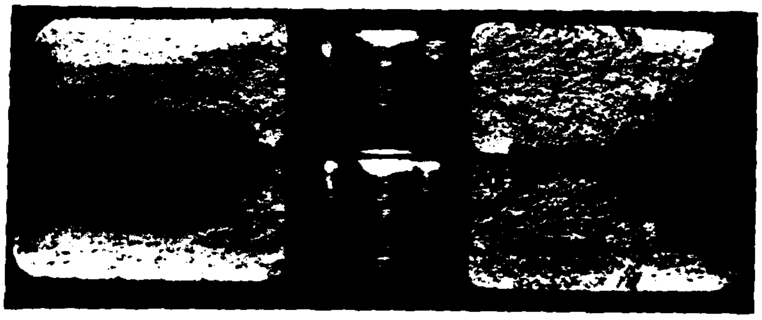
Sketch

14. Description of Abnormalities: None
15. Description of Buckling Restraint (If Used):

APPENDIX II

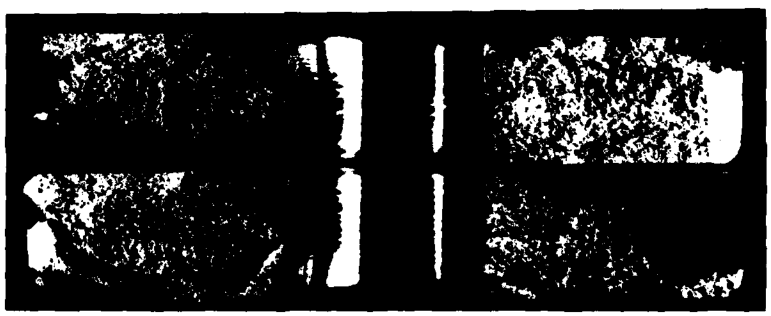
MACROGRAPHS OF FAILURE SURFACES

SPECIMEN AF-26



SPECIMEN BF-242

SPECIMEN BF-235



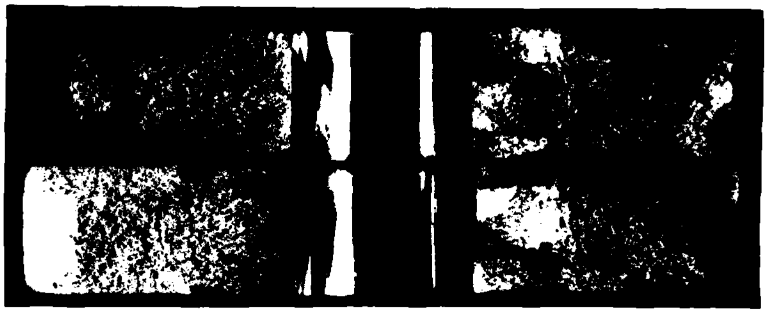
SPECIMEN BF-224

SPECIMEN AF-45

SPECIMEN AF-47

SPECIMEN BF-227

SPECIMEN AF-122

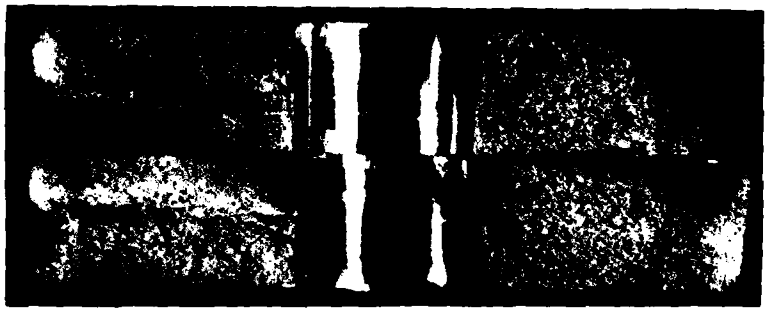


SPECIMEN BF-281

SPECIMEN AF-78

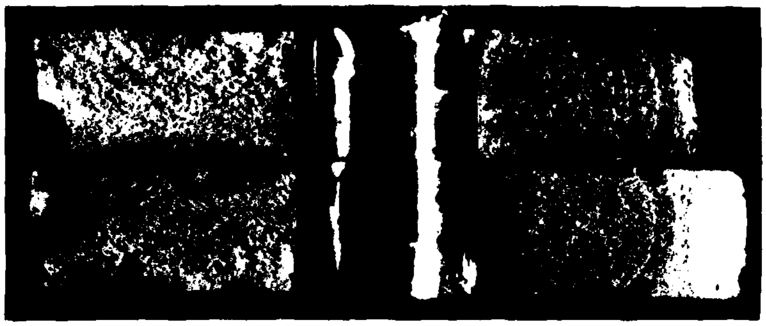
SPECIMEN AF-136

SPECIMEN BF-305

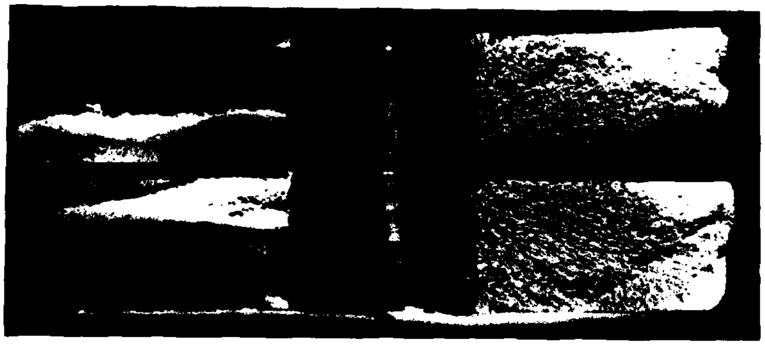


SPECIMEN BF-323

SPECIMEN BF-228



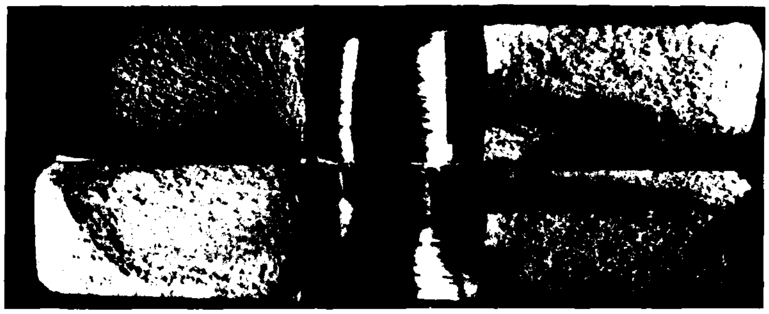
SPECIMEN AF-123



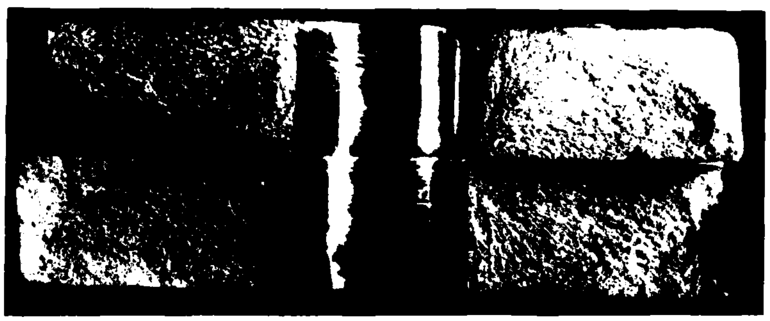
SPECIMEN AF-88

SPECIMEN AF-43

SPECIMEN AF-138



SPECIMEN AF-114



SPECIMEN BF-223

SPECIMEN AF-112

APPENDIX E

CRITICALLY LOADED HOLE TECHNOLOGY PILOT PROGRAM

PHASE III REPORT FOR PERIOD APRIL 1979 - AUGUST 1979

BATTELLE
COLUMBUS LABORATORIES
505 KING AVENUE
COLUMBUS, OHIO 43201

September 1979

METCUT RESEARCH ASSOCIATES, INC., PURCHASE ORDER NO. 65474

INTRODUCTION

A pilot program has been initiated by the AGARD SMP Subcommittee on Critically Loaded Hole Technology in an effort to promote a mutual confidence in fatigue test data generated by participating countries. The successful completion of the program will lead to a more uniform quality of fatigue testing and evaluation of critically loaded hole parameters among its participants. The objectives of the three-phase program are as follow:

- Phase I - Generate baseline, open hole, fatigue data in order to examine laboratory-to-laboratory variations
- Phase II - Reaffirm the exchangeability of baseline data and investigate the effect of hole quality on open hole fatigue specimens
- Phase III - Conduct independent fatigue evaluations of various fatigue-improvement fasteners and exchange data.

Participants in the program included representatives from Belgium, France, Germany, Italy, Netherlands, Sweden, United Kingdom, and the United States. All specimens for the program are to be prepared by Metcut Research Associates, Inc., from a single heat of 7050 material procured from Alcoa in the form of 7050-T76 bare sheet, 0.196-inch (5 mm) thick. Battelle's Columbus Laboratories (BCL) has been designated as the USA testing facility.

The report contained herein details the results of the Phase III effort.

GENERATION OF THE FALSTAFF SPECTRUM

In order to insure that all participants apply the same cyclic loads, each country was to test specimens under the FALSTAFF (Fighter Aircraft Loading STAndard For Fatigue). The BCL fatigue load control program was generated using the computer program detailed in the definitive description of the FALSTAFF spectrum, dated March 1976. The details of the BCL load control program generation were presented in the Phase I report dated February 1978.

PROGRAM CONTROL

This section describes the BCL system and equipment used to apply and control FALSTAFF program loads. In general, the HP 2100 computer provides load steps to a hybrid unit which generates a constant ramp rate function for the MTS 20,000-pound (88,960 N) closed-loop electrohydraulic fatigue machine. A null pacing unit makes a constant comparison of programmed load-to-load cell output and signals the hybrid unit when the programmed load has been reached, at which time the ramp direction is reversed and a new load is called from the computer. This procedure continues until a preprogrammed number of flights has been reached or until the test specimen fails. A graphic presentation of the program control cycle is presented in Figure 1. A secondary computer subroutine, STATS, makes it possible to determine the flight number, total number of cycles, and percent of a pass through the spectrum completed at the moment of questioning.

Pretest Checks

Prior to initiating the fatigue test program, pretest checks were made (as in Phase I) using the Phase I spare specimen (without a hole in the test section) instrumented with two strain gages located near the specimen edge on each face of the specimen. The output of the four strain gages made it possible to determine specimen bending and buckling (if any existed) and to confirm that dynamic loads matched static calibration loads.

Bending Check

Strain gage data were obtained at incremental load steps for loads to an equivalent of 38 ksi (262 MPa) maximum and -19 ksi (131 MPa) minimum. Data were obtained for three loading cycles. The strain-load data were submitted to a linear regression analysis with resulting R^2 statistic values ranging from 1.000 to .9994. Strain values were computed for the load equivalent of 30 ksi (206.85 MPa) gross stress. Analysis of the strain values indicated that the maximum error due to specimen bending was 2.60 percent. Analysis of the compressive load data indicated that no buckling could be detected.

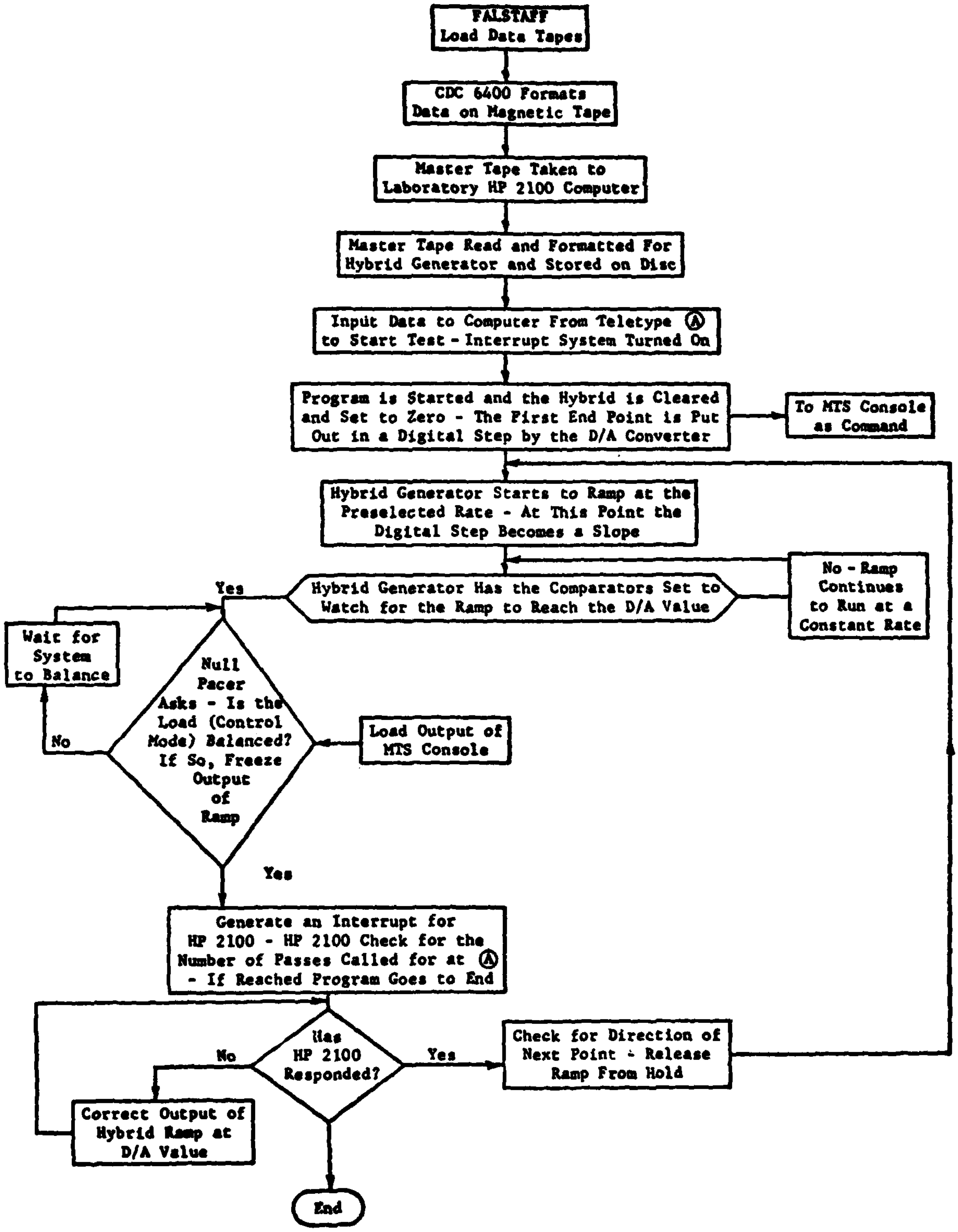


FIGURE 1. PROGRAM CONTROL CYCLE

Static-Dynamic Loads Check

Comparison of strain gage output and calibrated load cell output indicated a maximum axial load error of 1.50 percent at 38 ksi (262 MPa) static load. Application of cyclic loads at the same level provided the same strain outputs at frequencies of 1, 5, and 10 Hz.

FALSTAFF Loads Check

The specimen was subjected to FALSTAFF loads cycling and ramp rate and MTS uuit controls were adjusted so that fatigue machine load output matched the command signal (reference Figure 2). Once setup was complete the controls were locked and not changed during the rest of the test program. The mean cyclic rate was determined to be 10.5 Hz. In addition, staff members of the University of Dayton Research Institute made load and spectrum accuracy measurements. These data are reported separately.

TEST RESULTS

Fatigue Load Selection

Tests were conducted on specimens assembled by Metcut Research Associates. In order to determine a reference stress level for the low-load transfer specimen used in this Phase, these specimens were assembled using HiLok fasteners installed in a tight interference fit. Analysis of the data presented in Table I indicated that a reference stress of 51 ksi (351.6 MPa) would provide a fatigue life of approximately 10,000 FALSTAFF flights to failure.

TABLE I. LOAD LEVEL DETERMINATION

Specimen Number	Reference Stress, ksi/MPa	Flights to Failure
2	57.0/393.0	1,632
4	50.0/344.7	11,371
6	51.0/351.6	10,970
7	52.0/358.5	7,210

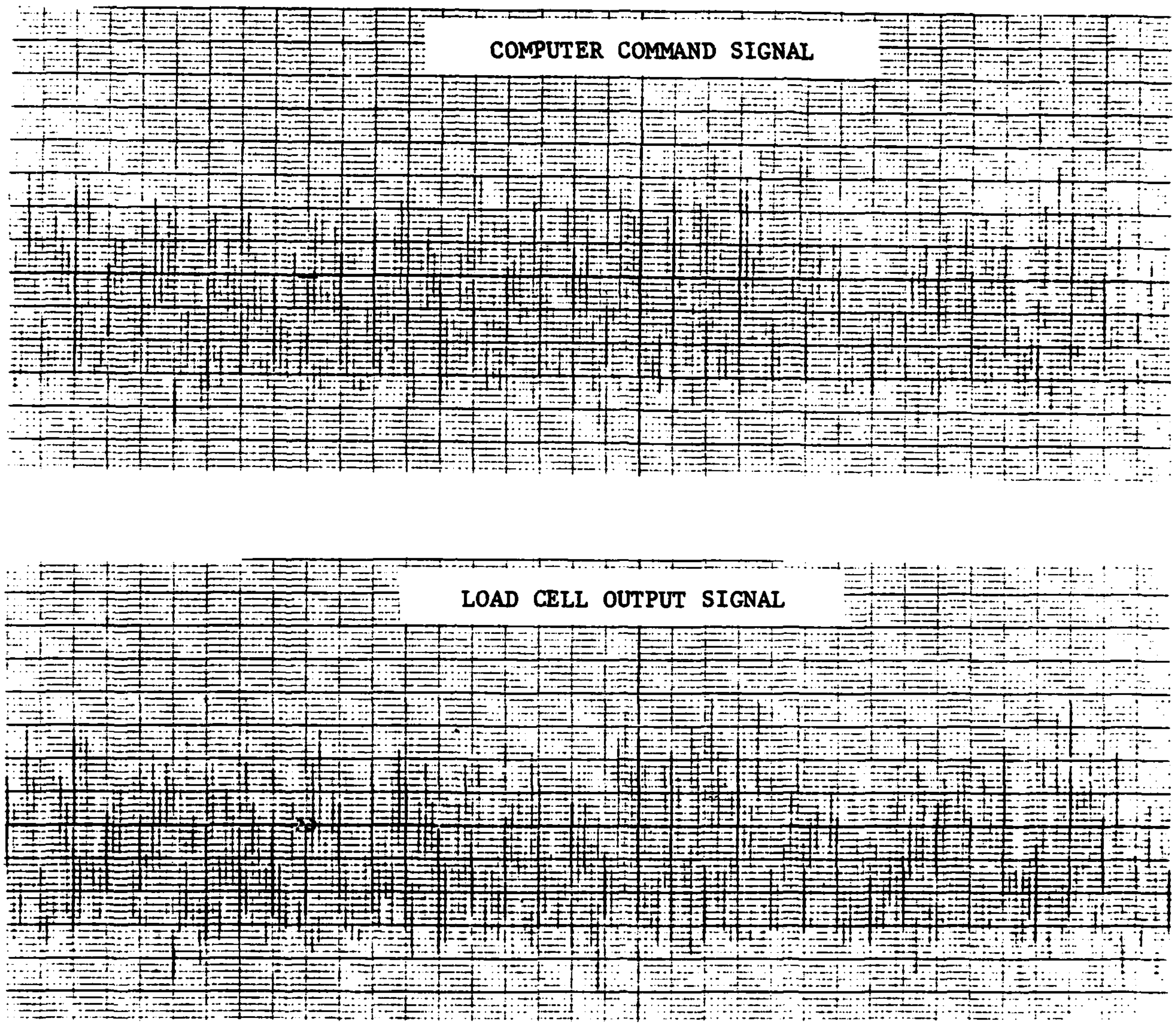


FIGURE 2. COMPUTER COMMAND AND LOAD CELL SIGNAL COMPARISON FOR A PORTION OF THE TEST ON SPECIMEN J8-J43

Fatigue Test Program

Fatigue test specimens, as supplied by Metcut Research Associates, Inc., were selected at random from all three specimen types (K-Lobe fasteners in high and low quality holes and blind fasteners). All specimens were cycled at a reference stress of 51.0 ksi (351.6 MPa). A summary of the fatigue test data is presented in Table II and detailed data sheets are included as an appendix to this report.

NOTE: The data for the blind fastener specimen J44-J54, which failed at 3,764 flights, is not tabulated because it was tested at 42 ksi (289.6 MPa) instead of the required level.

TABLE II. FATIGUE TEST RESULTS*

Specimen Number	Flights to Failure
K-Lobe in High-Quality Holes	
J41-J48	15,160
J20-J42	12,344
J8-J43	9,964
J2-J17	12,734
J45-J50	7,597
J25-J35	7,080
Mean Life	10,813
Standard Deviation	3,160
K-Lobe in Low-Quality Holes	
J4-J33	9,164
J18-J12	9.924
J47-J10	17,228
J22-J26	6,164
J13-J53	10,164
J2-J16	13,755
Mean Life	11,070
Standard Deviation	3,875
Blind Fasteners	
J32-J51	1,364
J6-J40	1,964
J5-J55	1,534
J7-J36	1,544
J24-J30	1,597
Mean Life	1,600
Standard Deviation	221

* FALSTAFF reference stress - 51 ksi (351.6 MPa)

APPENDIX 1

DETAILED DATA SHEETS

DATA SHEET

AIR FORCE/AFML - METCUT RESEARCH SPONSORED
AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: BATTELLE'S COLUMBUS LABORATORIES
STRUCTURAL MATERIALS AND TRIBOLOGY SECTION
STRUCTURAL FATIGUE LABORATORY

1. Date of Test: Start May 5, 1979 End May 6, 1979

2. Manufacture/Model of Fatigue Test Machine: MTS

3. Test Temperature: 70 °F (21 °C)

4. Relative Humidity: 42 (%)

5. Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)

51.0 ksi (351.6 MPa)

6. Specimen Identification: 8 (5A) J25-J35

7. Specimen Bending at Minimum Load: None %

8. Specimen Bending at RMS Mean Load: 2.6 %

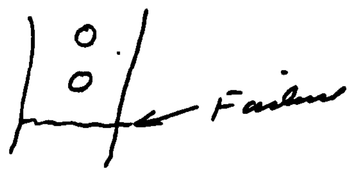
9. RMS Mean Cyclic Frequency: 10.5 Hz

10. Number of Flights to Initial Visible Crack: -- Flights

11. Size of Initial Visible Crack: -- in. (-- mm)

12. Number of Flights to Catastrophic Failure: 7080 Flights

13. Fatigue-Crack-Initiation Site: 3/8" below bottom fastener



Sketch

14. Description of Abnormalities: ____

15. Description of Buckling Restraint (If Used): ____

DATA SHEET

AIR FORCE/AFML - METCUT RESEARCH SPONSORED
AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: BATTELLE'S COLUMBUS LABORATORIES
STRUCTURAL MATERIALS AND TRIBOLOGY SECTION
STRUCTURAL FATIGUE LABORATORY

1. Date of Test: Start May 8, 1979 End May 9, 1979

2. Manufacture/Model of Fatigue Test Machine: MTS 50 KIP

3. Test Temperature: 70 °F (21 °C)

4. Relative Humidity: 42 (%)

5. Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)
51.0 ksi (351.6 MPa)

6. Specimen Identification: 5 J45-J50

7. Specimen Bending at Minimum Load: None %

8. Specimen Bending at RMS Mean Load: 2.6 %

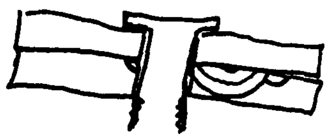
9. RMS Mean Cyclic Frequency: 10.5 Hz

10. Number of Flights to Initial Visible Crack: -- Flights

11. Size of Initial Visible Crack: -- in. (mm)

12. Number of Flights to Catastrophic Failure: 7597 Flights

13. Fatigue-Crack-Initiation Site: ______



Sketch

14. Description of Abnormalities: ______

15. Description of Buckling Restraint (If Used): ______

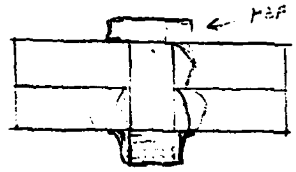
DATA SHEET

AIR FORCE/AFML - METCUT RESEARCH SPONSORED
AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: BATTELLE'S COLUMBUS LABORATORIES
STRUCTURAL MATERIALS AND TRIBOLOGY SECTION
STRUCTURAL FATIGUE LABORATORY

1. Date of Test: Start July 13, 1979 End July 13, 1979
2. Manufacture/Model of Fatigue Test Machine: MTS 50 KIP
3. Test Temperature: 70 °F (21 °C)
4. Relative Humidity: 50 (%)
5. Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)

   51.0 ksi (351.6 MPa)
6. Specimen Identification: 10 J24-J30
7. Specimen Bending at Minimum Load: None %
8. Specimen Bending at RMS Mean Load: 2.6 %
9. RMS Mean Cyclic Frequency: 10.5 Hz
10. Number of Flights to Initial Visible Crack: -- Flights
11. Size of Initial Visible Crack: -- in. (mm)
12. Number of Flights to Catastrophic Failure: 1597 Flights
13. Fatigue-Crack-Initiation Site: ____________



Sketch

14. Description of Abnormalities: ____________
15. Description of Buckling Restraint (If Used): ____________

DATA SHEET

AIR FORCE/AFML - METCUT RESEARCH SPONSORED
AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: BATTELLE'S COLUMBUS LABORATORIES
STRUCTURAL MATERIALS AND TRIBOLOGY SECTION
STRUCTURAL FATIGUE LABORATORY

1. Date of Test: Start July 16, 1979 End July 17, 1979

2. Manufacture/Model of Fatigue Test Machine: MTS 50 KIP

3. Test Temperature: 70 °F (21 °C)

4. Relative Humidity: 50 (%)

5. Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)
42.0 ksi (289.6 MPa)

6. Specimen Identification: 11 J44-J54

7. Specimen Bending at Minimum Load: None %

8. Specimen Bending at RMS Mean Load: 2.6 %

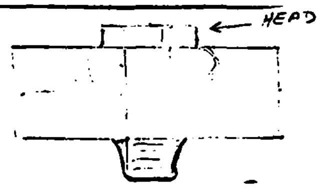
9. RMS Mean Cyclic Frequency: 10.5 Hz

10. Number of Flights to Initial Visible Crack: -- Flights

11. Size of Initial Visible Crack: -- in. (mm)

12. Number of Flights to Catastrophic Failure: 3764 Flights

13. Fatigue-Crack-Initiation Site:



Sketch

14. Description of Abnormalities: Wrong Stress

15. Description of Buckling Restraint (If Used):

DATA SHEET

AIR FORCE/AFML - METCUT RESEARCH SPONSORED
AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: BATTELLE'S COLUMBUS LABORATORIES
STRUCTURAL MATERIALS AND TRIBOLOGY SECTION
STRUCTURAL FATIGUE LABORATORY

1. Date of Test: Start July 17, 1979 End July 18, 1979

2. Manufacture/Model of Fatigue Test Machine: MTS 50 KIP

3. Test Temperature: 69 °F (20 °C)

4. Relative Humidity: 49 (%)

5. Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)

51 ksi (351.6 MPa)

6. Specimen Identification: 12 J4-J33

7. Specimen Bending at Minimum Load: None %

8. Specimen Bending at RMS Mean Load: 2.6 %

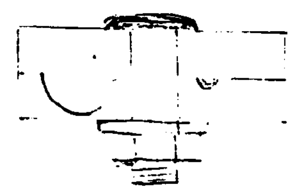
9. RMS Mean Cyclic Frequency: 10.5 Hz

10. Number of Flights to Initial Visible Crack: -- Flights

11. Size of Initial Visible Crack: -- in. (mm)

12. Number of Flights to Catastrophic Failure: 9,164.06 Flights

13. Fatigue-Crack-Initiation Site:



Sketch

14. Description of Abnormalities:

15. Description of Buckling Restraint (If Used):

DATA SHEET

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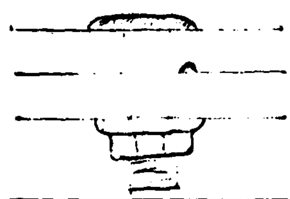
AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: BATTELLE'S COLUMBUS LABORATORIES
STRUCTURAL MATERIALS AND TRIBOLOGY SECTION
STRUCTURAL FATIGUE LABORATORY

1. Date of Test: Start July 18, 1979 End July 19, 1979
2. Manufacture/Model of Fatigue Test Machine: MTS 50 KIP
3. Test Temperature: 71 °F (22 °C)
4. Relative Humidity: 42 (%)
5. Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)

   51 ksi (351.6 MPa)
6. Specimen Identification: 13 J18-J12
7. Specimen Bending at Minimum Load: None %
8. Specimen Bending at RMS Mean Load: 2.6 %
9. RMS Mean Cyclic Frequency: 10.5 Hz
10. Number of Flights to Initial Visible Crack: -- Flights
11. Size of Initial Visible Crack: -- in. (mm)
12. Number of Flights to Catastrophic Failure: 9,923.66 Flights
13. Fatigue-Crack-Initiation Site:



Sketch

14. Description of Abnormalities:

15. Description of Buckling Restraint (If Used):

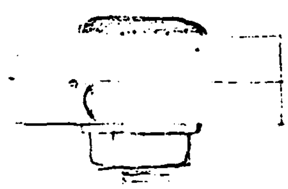
DATA SHEET

AIR FORCE/AFML - METCUT RESEARCH SPONSORED
AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: BATTELLE'S COLUMBUS LABORATORIES
STRUCTURAL MATERIALS AND TRIBOLOGY SECTION
STRUCTURAL FATIGUE LABORATORY

1. Date of Test: Start July 19, 1979 End July 20, 1979
2. Manufacture/Model of Fatigue Test Machine: MTS 50 KIP
3. Test Temperature: 70 °F (21 °C)
4. Relative Humidity: 40 (%)
5. Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)

   51 ksi (351.6 MPa)
6. Specimen Identification: 14 J47-J10
7. Specimen Bending at Minimum Load: None %
8. Specimen Bending at RMS Mean Load: 2.6 %
9. RMS Mean Cyclic Frequency: 10.5 Hz
10. Number of Flights to Initial Visible Crack: -- Flights
11. Size of Initial Visible Crack: -- in. (mm)
12. Number of Flights to Catastrophic Failure: 17,228.46 Flights
13. Fatigue-Crack-Initiation Site: ______



Sketch

14. Description of Abnormalities: ______
15. Description of Buckling Restraint (If Used): ______

DATA SHEET

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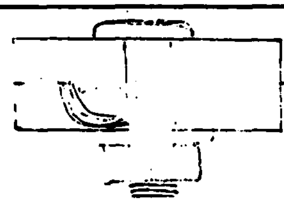
AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: BATTELLE'S COLUMBUS LABORATORIES
STRUCTURAL MATERIALS AND TRIBOLOGY SECTION
STRUCTURAL FATIGUE LABORATORY

1. Date of Test: Start July 20, 1979 End July 21, 1979
2. Manufacture/Model of Fatigue Test Machine: MTS 50 KIP
3. Test Temperature: 70 °F (21 °C)
4. Relative Humidity: 44 (%)
5. Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)
   51 ksi (351.6 MPa)
6. Specimen Identification: 15 J22-J26
7. Specimen Bending at Minimum Load: None %
8. Specimen Bending at RMS Mean Load: 2.6 %
9. RMS Mean Cyclic Frequency: 10.5 Hz
10. Number of Flights to Initial Visible Crack: -- Flights
11. Size of Initial Visible Crack: -- in. (mm)
12. Number of Flights to Catastrophic Failure: 6,164.42 Flights
13. Fatigue-Crack-Initiation Site:



Sketch

14. Description of Abnormalities:
15. Description of Buckling Restraint (If Used):

DATA SHEET

AIR FORCE/AFML - METCUT RESEARCH SPONSORED
AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: BATTELLE'S COLUMBUS LABORATORIES
STRUCTURAL MATERIALS AND TRIBOLOGY SECTION
STRUCTURAL FATIGUE LABORATORY

1. Date of Test: Start July 21, 1979 End July 22, 1979

2. Manufacture/Model of Fatigue Test Machine: MTS 50 KIP

3. Test Temperature: 70 °F (21 °C)

4. Relative Humidity: 47 (%)

5. Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)

51 ksi (351.6 MPa)

6. Specimen Identification: 16 J13-J53

7. Specimen Bending at Minimum Load: None %

8. Specimen Bending at RMS Mean Load: 2.6 %

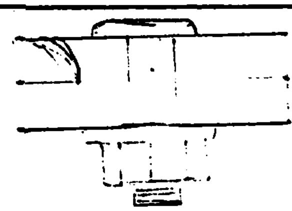
9. RMS Mean Cyclic Frequency: 10.5 Hz

10. Number of Flights to Initial Visible Crack: -- Flights

11. Size of Initial Visible Crack: -- in. (mm)

12. Number of Flights to Catastrophic Failure: 10,164.42 Flights

13. Fatigue-Crack-Initiation Site:



Sketch

14. Description of Abnormalities:

15. Description of Buckling Restraint (If Used):

DATA SHEET

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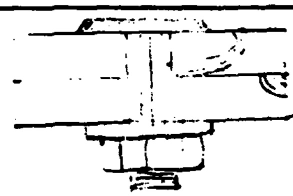
AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: BATTELLE'S COLUMBUS LABORATORIES
STRUCTURAL MATERIALS AND TRIBOLOGY SECTION
STRUCTURAL FATIGUE LABORATORY

1. Date of Test: Start July 23, 1979 End July 24, 1979
2. Manufacture/Model of Fatigue Test Machine: 50 KIP MTS
3. Test Temperature: 70 °F (21 °C)
4. Relative Humidity: 50 (%)
5. Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)

   51 ksi (351.6 MPa)
6. Specimen Identification: 17 J2-J16
7. Specimen Bending at Minimum Load: None %
8. Specimen Bending at RMS Mean Load: 2.6 %
9. RMS Mean Cyclic Frequency: 10.5 Hz
10. Number of Flights to Initial Visible Crack: -- Flights
11. Size of Initial Visible Crack: -- in. (mm)
12. Number of Flights to Catastrophic Failure: 13,754.98 Flights
13. Fatigue-Crack-Initiation Site:



Sketch

14. Description of Abnormalities:
15. Description of Buckling Restraint (If Used):

DATA SHEET

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AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: BATTELLE'S COLUMBUS LABORATORIES
STRUCTURAL MATERIALS AND TRIBOLOGY SECTION
STRUCTURAL FATIGUE LABORATORY

1. Date of Test: Start July 24, 1979 End ________

2. Manufacture/Model of Fatigue Test Machine: 50 KIP MTS

3. Test Temperature: 70 °F (21 °C)

4. Relative Humidity: 50 (%)

5. Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)
   51 ksi (351.6 MPa)

6. Specimen Identification: 6 J32-J51

7. Specimen Bending at Minimum Load: None %

8. Specimen Bending at RMS Mean Load: 2.6 %

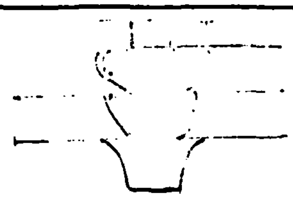
9. RMS Mean Cyclic Frequency: 10.5 Hz

10. Number of Flights to Initial Visible Crack: -- Flights

11. Size of Initial Visible Crack: -- in. (________ mm)

12. Number of Flights to Catastrophic Failure: 1,364.06 Flights

13. Fatigue-Crack-Initiation Site: ________



Sketch

14. Description of Abnormalities: ________

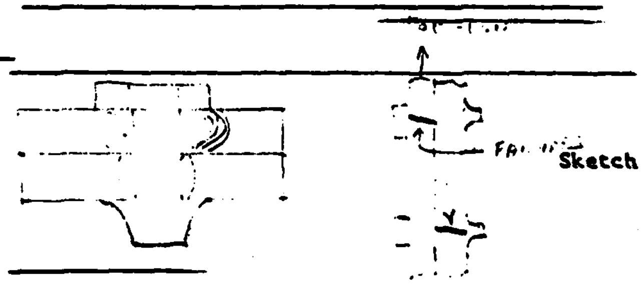
15. Description of Buckling Restraint (If Used): ________

DATA SHEET

AIR FORCE/AFML - METCUT RESEARCH SPONSORED
AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: BATTELLE'S COLUMBUS LABORATORIES
STRUCTURAL MATERIALS AND TRIBOLOGY SECTION
STRUCTURAL FATIGUE LABORATORY

1. Date of Test: Start July 24, 1979 End July 25, 1979
2. Manufacture/Model of Fatigue Test Machine: MTS 50 KIP
3. Test Temperature: 70 °F (21 °C)
4. Relative Humidity: 50 (%)
5. Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)
   51 ksi (351.6 MPa)
6. Specimen Identification: 7 J6-J40
7. Specimen Bending at Minimum Load: None %
8. Specimen Bending at RMS Mean Load: 2.6 %
9. RMS Mean Cyclic Frequency: 10.5 Hz
10. Number of Flights to Initial Visible Crack: -- Flights
11. Size of Initial Visible Crack: -- in. (mm)
12. Number of Flights to Catastrophic Failure: 1,964.06 Flights
13. Fatigue-Crack-Initiation Site:



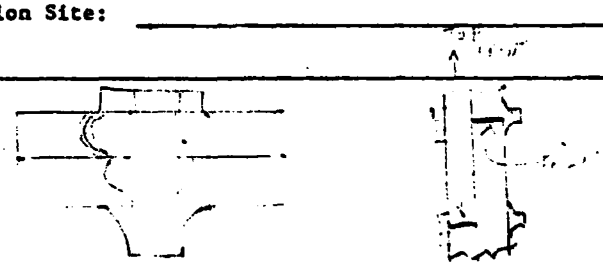
14. Description of Abnormalities:
15. Description of Buckling Restraint (If Used):

DATA SHEET

AIR FORCE/AFML - METCUT RESEARCH SPONSORED
AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: BATTELLE'S COLUMBUS LABORATORIES
STRUCTURAL MATERIALS AND TRIBOLOGY SECTION
STRUCTURAL FATIGUE LABORATORY

1. Date of Test: Start July 25, 1979 End July 25, 1979
2. Manufacture/Model of Fatigue Test Machine: 50 KIP MTS
3. Test Temperature: 70 °F (21 °C)
4. Relative Humidity: 52 (%)
5. Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)
   51 ksi (351.6 MPa)
6. Specimen Identification: 8 J5-J55
7. Specimen Bending at Minimum Load: -- %
8. Specimen Bending at RMS Mean Load: 2.6 %
9. RMS Mean Cyclic Frequency: 10.5 Hz
10. Number of Flights to Initial Visible Crack: -- Flights
11. Size of Initial Visible Crack: -- in. (mm)
12. Number of Flights to Catastrophic Failure: 1,534.34 Flights
13. Fatigue-Crack-Initiation Site:



Sketch

14. Description of Abnormalities:

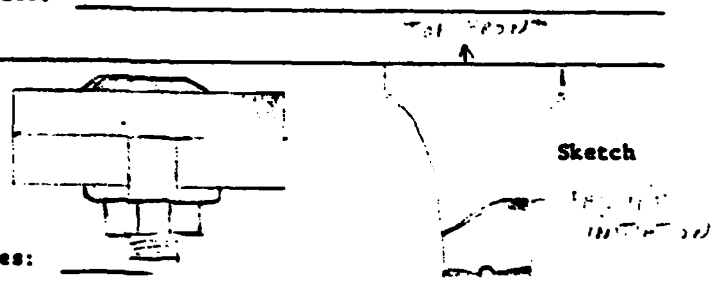
15. Description of Buckling Restraint (If Used):

DATA SHEET

AIR FORCE/AFML - METCUT RESEARCH SPONSORED
AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: BATTELLE'S COLUMBUS LABORATORIES
STRUCTURAL MATERIALS AND TRIBOLOGY SECTION
STRUCTURAL FATIGUE LABORATORY

1. Date of Test: Start July 25, 1979 End July 27, 1979
2. Manufacture/Model of Fatigue Test Machine: MTS 50 KIP
3. Test Temperature: 70 °F (21 °C)
4. Relative Humidity: 52 (%)
5. Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)
   51 ksi (351.6 MPa)
6. Specimen Identification: 1 J41-J48
7. Specimen Bending at Minimum Load: — %
8. Specimen Bending at RMS Mean Load: 2.6 %
9. RMS Mean Cyclic Frequency: 10.5 Hz
10. Number of Flights to Initial Visible Crack: -- Flights
11. Size of Initial Visible Crack: — in. (mm)
12. Number of Flights to Catastrophic Failure: 15,160.5 Flights
13. Fatigue-Crack-Initiation Site: ______



Sketch

14. Description of Abnormalities: ______
15. Description of Buckling Restraint (If Used): ______

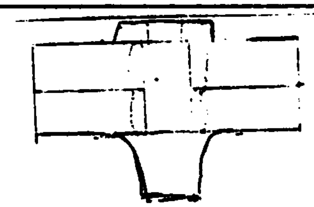
DATA SHEET

AIR FORCE/AFML - METCUT RESEARCH SPONSORED
AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: BATTELLE'S COLUMBUS LABORATORIES
STRUCTURAL MATERIALS AND TRIBOLOGY SECTION
STRUCTURAL FATIGUE LABORATORY

1. Date of Test: Start July 27, 1979 End July 27, 1979
2. Manufacture/Model of Fatigue Test Machine: MTS 50 KIP
3. Test Temperature: 68 °F (20 °C)
4. Relative Humidity: 50 (%)
5. Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)

   51 ksi (351.6 MPa)
6. Specimen Identification: 9 J7-J36
7. Specimen Bending at Minimum Load: -- %
8. Specimen Bending at RMS Mean Load: 2.6 %
9. RMS Mean Cyclic Frequency: 10.5 Hz
10. Number of Flights to Initial Visible Crack: -- Flights
11. Size of Initial Visible Crack: -- in. (mm)
12. Number of Flights to Catastrophic Failure: 1,564.06 Flights
13. Fatigue-Crack-Initiation Site:



Sketch

14. Description of Abnormalities:
15. Description of Buckling Restraint (If Used):

DATA SHEET

AIR FORCE/AFML - METCUT RESEARCH SPONSORED
AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: BATTELLE'S COLUMBUS LABORATORIES
STRUCTURAL MATERIALS AND TRIBOLOGY SECTION
STRUCTURAL FATIGUE LABORATORY

1. Date of Test: Start July 27, 1979 End July 28, 1979

2. Manufacture/Model of Fatigue Test Machine: MTS 50 KIP

3. Test Temperature: 68 °F (20 °C)

4. Relative Humidity: 50 (%)

5. Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)
51 ksi (351.6 MPa)

6. Specimen Identification: 2 J2-J42

7. Specimen Bending at Minimum Load: -- %

8. Specimen Bending at RMS Mean Load: 2.6 %

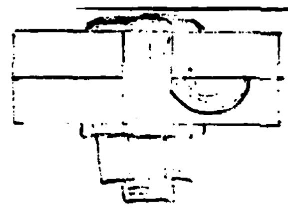
9. RMS Mean Cyclic Frequency: 10.5 Hz

10. Number of Flights to Initial Visible Crack: -- Flights

11. Size of Initial Visible Crack: -- in. (mm)

12. Number of Flights to Catastrophic Failure: 12,344.12 Flights

13. Fatigue-Crack-Initiation Site: ______



Sketch

14. Description of Abnormalities: ______

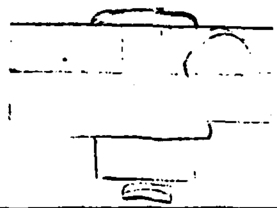
15. Description of Buckling Restraint (If Used): ______

DATA SHEET

AIR FORCE/AFML - METCUT RESEARCH SPONSORED
AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: BATTELLE'S COLUMBUS LABORATORIES
STRUCTURAL MATERIALS AND TRIBOLOGY SECTION
STRUCTURAL FATIGUE LABORATORY

1. Date of Test: Start July 30, 1979 End July 31, 1979
2. Manufacture/Model of Fatigue Test Machine: MTS 50 KIP
3. Test Temperature: 68 °F (20 °C)
4. Relative Humidity: 50 (%)
5. Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)
51 ksi (351.6 MPa)
6. Specimen Identification: 3 J8-J43
7. Specimen Bending at Minimum Load: -- %
8. Specimen Bending at RMS Mean Load: 2.6 %
9. RMS Mean Cyclic Frequency: 10.5 Hz
10. Number of Flights to Initial Visible Crack: -- Flights
11. Size of Initial Visible Crack: -- in. (mm)
12. Number of Flights to Catastrophic Failure: 9,964.06 Flights
13. Fatigue-Crack-Initiation Site:



Sketch

14. Description of Abnormalities:

15. Description of Buckling Restraint (If Used):

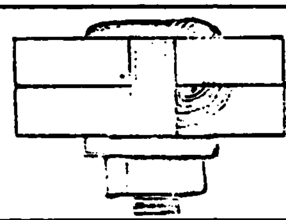
DATA SHEET

AIR FORCE/AFML - METCUT RESEARCH SPONSORED
AGARD CRITICALLY LOADED HOLE TECHNOLOGY PROGRAM

TESTS CONDUCTED BY: BATTELLE'S COLUMBUS LABORATORIES
STRUCTURAL MATERIALS AND TRIBOLOGY SECTION
STRUCTURAL FATIGUE LABORATORY

1. Date of Test: Start July 31, 1979 End ________
2. Manufacture/Model of Fatigue Test Machine: MTS 50 KIP
3. Test Temperature: 70 °F (21 °C)
4. Relative Humidity: 50 (%)
5. Reference (Gross) Stress Level of FALSTAFF Spectrum (Step 32)

   51 ksi (351.6 MPa)
6. Specimen Identification: 4 J2-J17
7. Specimen Bending at Minimum Load: -- %
8. Specimen Bending at RMS Mean Load: 2.6 %
9. RMS Mean Cyclic Frequency: 10.5 Hz
10. Number of Flights to Initial Visible Crack: -- Flights
11. Size of Initial Visible Crack: -- in. (________ mm)
12. Number of Flights to Catastrophic Failure: 12,734.34 Flights
13. Fatigue-Crack-Initiation Site: ________



Sketch

14. Description of Abnormalities: ________
15. Description of Buckling Restraint (If Used): ________

APPENDIX F

APPENDIX

VERIFICATION OF LOADING ACCURACY FOR FALSTAFF LOAD SEQUENCE

As a part of the critically loaded hole program, the University of Dayton, USA, conducted a program to determine whether or not all participating countries were applying identical spectrum load levels at the agreed-to reference stress level.

A.1 METHOD OF VERIFICATION

The evaluation was conducted using a master load cell specimen which replaced the standard test specimen (Phase III) in the fatigue machine. Each participating laboratory applied one complete spectrum (200 flights) of FALSTAFF to the master load cell specimen using the same servo control and program setup as was used for the Phase III low load transfer specimen.

A histogram recorder (data acquisition system) was used to record the number of load reversals that occurred within a narrow range of the load. The band width for each range was one-fourth of a FALSTAFF load level. The recorder had 128 storage locations for the reversals that were peaks and 128 storage locations for the reversals that were valleys. A schematic diagram of the recording system is shown in Figure A.1.

A.2 DESCRIPTION AND FUNCTION OF EQUIPMENT

A.2.1 Master Load Cell Specimen

The master load cell specimen was designed to fit in the testing machines without any modification to the grip arrangement. The specimen was designed so that it had the same stiffness as the reverse double dog-bone low load transfer test specimen.

The master load cell specimen had two strain gage bridges; one of the bridges was calibrated traceable to the USA

Bureau of Standards and was used to calibrate the second bridge and the histogram recorder.

A.2.2 Histogram Recorder

The histogram recorder was a Sun Systems, Inc. ADASTOR II Solid State Recorder with duplicate sections for the peak and valley histograms. The recorder had two analog to digital converters and two microprocessors, one each for the peak recorder and one for the valley recorder. The fact that there were two analog to digital converters and two processors caused some confusion because the number of peaks recorded did not always equal the number of valleys recorded. We expected that the number of peaks would have to equal the number of valleys since the program for the peaks was the same as for the valleys. The only reason for any difference would have to be due to a different requirement for the change in load to define a peak than to define a valley. Both recorders were programmed to require a change in load of 1.5 FALSTAFF steps to define a peak or valley.

During the recording phase of the program, there were several times when many more valleys than peaks were recorded. This difficulty was thought to be caused by low battery voltage, however, after the recording program was completed the ADASTOR II was returned to Sun Systems for analysis. Sun Systems reported that the analog to digital converter on the valley recorder was adding electronic noise to the signal and then processed by the microprocessor. Sun Systems replaced the A-D converter in the valley recorder and since that time we have not had any extra readings in the valley recorder. We have just now used the recorder on a test that lasted seven hours without a single error by the recorder and without recharging the batteries.

The introduction of the noise on the valley recorder signal may have caused some valleys to be recorded at a lower value than was actually applied to the specimen and we know that it caused additional valleys to be recorded. For these reasons we have not reported all of the valley data for one country.

A.3 RESULTS

The results of the study are presented in Table A.1. The first column in the table (labeled FALSTAFF) lists the expected number of peaks or valleys at the particular FALSTAFF load level. Note that all of these levels are integer levels. The other seven columns are the recordings from the seven countries that participated in the program.

In the following presentation of the results, no comments will be made, with reference to any one laboratory, about load levels seven and eight for the peaks and load levels five and six for the valleys. The zero load level for the FALSTAFF sequence is 7.527 and the first load in the sequence is level eight and the last load level in flight 200 is load level six. Because the various laboratories used different initial values before the sequence was started and also different techniques to stop after 200 flights, there was the problem of perhaps not having the first or last load reversal. In some laboratories, it was also possible that one or two of the taxi cycles were too small for the histogram recorder to identify a peak or valley. The taxi cycles were equal to two FALSTAFF levels and the histogram recorder required 1-1/2 levels to identify a peak or valley. Actually most countries had the exact number of peaks or valleys for levels five, six, seven, and eight and those that didn't were only in error by one or two counts.

I have banded the data by FALSTAFF load levels.

A.3.1 Countries 1, 2, 3, and 6

As one can see from an examination of the data in Table A.1, there doesn't appear to be any question about which programmed load levels correlate with the histogram recordings for the first three countries and Country No. 6.

A.3.2 Country 4

For Country No. 4, there is a question about the peaks at load levels 16 and 17 since load level 16 has five

extra peaks and load level 17 has five too few peaks, also load level 12 has two extra peaks whereas load level 13 is missing two. There is no way from the histogram data to conclude if these loads are programmed incorrectly or if the incorrect load was applied by the hydraulics or for that matter if the histogram recorder assigned these few peaks to the wrong memory cell. The valley data for column four also shows an extra valley in load level 12 and one too few at load level 13. Because there isn't any separation between the valley recording at load levels 12 and 13 it is impossible to say whether one of the recordings (counts) at load level 12.25 was programmed for load level 13 or load level 12. The number 28 recorded for load level 12.25 could be interpreted as one valley intended for level 13 and 27 intended for load level 12.

A.3.3 Country 5

The histogram recordings reported in column five required more deduction to assign the numbers to the bands. The first page of peaks has a one to one correspondence between the expected and recorded numbers. The recordings at load levels 15.5, 16.5, 17.5, 18.5, and 19.5 had to be divided between the next higher and lower integer levels to make the histograms correlate. The difficulty here is that one cannot say if some of the peaks recorded at 15.25, 16.25, 17.25, 18.25, and 19.25 were not programmed to be at the next higher integer level, however, since at the other load levels there was not this great a variation we assumed that the overlap was only in the one level, i.e., half way between the integer levels. This assumption made all of the recordings correlate with the expected values except load level 15 was one short and load level 13 was two short. The same procedure was used for the valleys. All of the recordings could be assigned to one of the load levels except level 12 was short four valleys.

A.3.4 Country 7

The data from Country No. 7 is the only set which contains an excess of counts in the peaks recorder. Some load levels contained the correct number of peaks (levels 32, 30, 29,

25, 22, 8, and 7) and some other levels were only off a few counts (levels 26, 21, 18, 14, 13). Based on the number of load levels that had the correct or nearly correct number of peaks, I think one can state that the spectrum generation was correct and that the hydraulic-servo system was capable of applying the correct load levels. There does appear to be a question as to what caused the extra counts in the peak recorder. At no other time, before or after this recording, did we get extra counts in the peak recorder. It is possible that the recorder malfunctioned or that the hydraulic-servo system was introducing a vibration in the system. Since only certain load levels were involved, it could be that the vibration was frequency dependent since the frequency used was a function of the range of the load change.

The histogram of the valleys was more irradic than the one for the peaks and had many more recordings than the peaks. Some of the load levels were correct (levels 24, 23, 20, 19, 17, 16, 3, 2, and 1) the other load levels except for level 18 had too many valleys. Some of these extra recordings could be due to the noise on the analog to digital converter and some of them could be due to a vibration in the test machine.

The data from Country No. 7 is not as meaningful as the others since the servovalve system used with the test machine and the spectrum frequency were not the same as was used for the Phase III test program.

A.4 DISCUSSION

The general conclusion from the verification program is that the various participating laboratories do quite a good job of applying spectrum loads.

Country No. 1 was excellent.

Country No. 2 was also excellent but with the peaks biased toward the high side and the valleys toward the low side. Too much span.

TABLE A.1. FALSTAFF HISTOGRAMS

PEAKS

	Falstaff	1	2	3	4	5	6	7
33								
32.5								
32								
31.5								
31								
30.5							1	
30	7	7	7	1 6	7	6 1	6	
29.5								5
29	10	10	10	1 10		10	1	2
28.5					21			
28	24	24	15 9	2 22	3	13 9 2	10 14	6
27.5					35		1	20
27	45	45	45	1 44	10	2 42 1	10 6	5 6
26.5					59		1	39
26	76	76	8 68	6 70	16 1	40 31 4	71 4	
25.5					80	1		67
25	104	104	97 7	8 96	24	81 13 10	93 20	9 1
24.5					119			101
24	193	2 191	193	11 182	72 2	118 61 12	155 38	1 3 64
23.5					98	2		188
23	233	233	22 211	17 216	120 9	157 52 21	200 27	6 37 61
22.5					81	1		231
22	404	404	325 79	26 378	298 25	253 115 31	322 82	7
21.5						5		393 4

TABLE A.1. FALSTAFF HISTOGRAMS

PEAKS CONTINUED

	Falstaff	1	2	3	4	5	6	7
21.5					267			
			532		241	272	404	
21	533	533	1	35	25	191	129	
				498		57		30
20.5					67	13		495
			640		510	267	511	9
20	640	640		65	63	256	129	199
				575		109		216
19.5					24	8 4		580
			954		787	364	737	4
19	954	954		72	142	452	216	303
				882	1	116	1	441
18.5					33	18 12		686
			349		801	428	743	3
18	987	987	638	53	153	416	241	
				934		122	3	402
17.5						9 10		586
			978		809	370	938	1
17	1151	1151	173	47	328	599	213	1
				1104	9	156		645
16.5						16 5		508
			1244		764	313	930	6
16	1282	1282	38	38	514	731	350	672
				1244	9	205	2	1119
15.5						28 9		279
			1997		1153	188	1523	2
15	1999	1999	2	12	837	1423	476	775
				1987	9	370		1758
14.5						8		358
			5		2898	144	3903	
14	4145	3896	4140	64	1245	3199	241	2
		249		4081	2	780	1	3819
13.5						22		325
			6		1670	72	3949	
13	4058	3732	4052	70	2381	3146	109	127
		326		3988	5	835		3867
12.5						3		61
			5		128	12	486	
12	493	446	488	3	364	385	7	1290
		47		490	3	96		511
11.5								
			3		9	2	43	346
11	43	39	40		34	24		292
		4		43		17		24
10.5								
10								

TABLE A.1. FALSTAFF HISTOGRAMS
PEAKS CONCLUDED

	Falstaff	1	2	3	4	5	6	7
9.5								
9								
8.5								
					303			
8	445	182	444		142	142	441	368
		263	1	440		274	4	76
7.5				4		27		1
					155			
7	155	155	155			155	152	150
				153			2	
6.5				1				

TABLE A.1. FALSTAFF HISTOGRAMS

VALLEYS

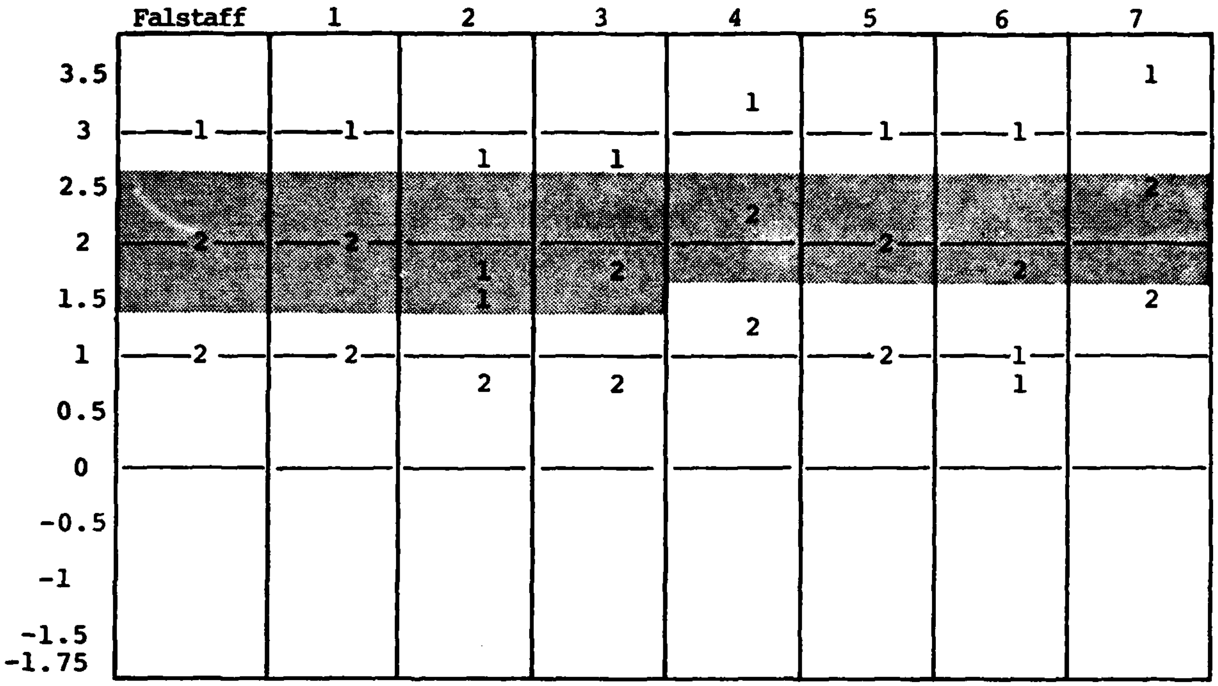
	Falstaff	1	2	3	4	5	6	7
26								
25.5								
		1	1					
25	1				1	1	1	
				1				
24.5							1	
		2	2		1			
24	2				1	1	1	
				2		1		
23.5							1	2
		3	1				1	
23	3		2		3	1	1	
				3		2		3
22.5							3	
		3	1		1		1	
22	4	1	3		2	3		
				4				16
21.5					1	1	4	4
		10	10		5		2	
21	12	2	2		7	10	6	5
				12		2		25
20.5							9	2
		12	22		8	7	3	1
20	23	11	1		12	9	11	8
				23	3	5		15
19.5						2	7	
		23	36		6	11	4	
19	37	14	1		26	16	26	18
				37	4	6		19
18.5					1	2	3	
		41	1		15	2 13	5	
18	69	28	68		41	31	61	49
				69	12	17		18
17.5					1	5	1	
		15	6		14	3 37	10	
17	135	120	129		99	71	124	109
				132	18	16		20
16.5				3	4	9		4
		10	23		9	2 36	20	2
16	234	224	211		170	108	214	225
				232	46	69		9
15.5				2	9	19		
		7	104		6	2 62	28	4
15	327	320	223		239	144	299	305
				322	59	88		8
14.5				5	23	33		

TABLE A.1. FALSTAFF HISTOGRAMS
VALLEYS CONTINUED

	Falstaff	1	2	3	4	5	6	7
14.5								
					44	74	42	17
14	511	511	425		326	226	469	471
			86	506	132	169		80
13.5				5	9	42		
					18	82	65	
13	716	716	619		472	328	651	
			97	697	206	232		
12.5				19	19	73		
					28	1 193	75	
12	1445	1445	1290		992	766	1364	
			155	1404	385	381	6	
11.5				41	41	101 6		
					49	1154	104	
11	4387	4387	3884		3353	2206	2528	
			503	4228	906	829	1755	
10.5				159	79	192 24		
					12	2143	48	
10	6711	6709	6180		5678	3789	3139	
		2	531	6425	926	634	3524	
9.5				286	95	121 2		
					3	324	23	
9	1941	1941	29		1382	1194	1078	
			1911	1860	525	375	840	
8.5			1	81	31	46 1		
						33	12	
8	543	543	28		190	306	288	
			515	530	343	200	243	
7.5				13	10	3		
		1			31	1	2	
7	36	35	7		5	18	21	
			29	36		17	13	
6.5						26		
		266			441	269	2	
6	508	243	508	41	67	158	368	
				435		54	137	
5.5				31				
		182			269	309		
5	327	145			58	11	144	
			161	321		7	183	
4.5			166	4				
		5			3			
4	6	1			3	2		
			5	6		4	6	
3.5			1					

TABLE A.1. FALSTAFF HISTOGRAMS

VALLEYS CONCLUDED



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